SEDIMENTARY IRON IN THE CRETACEOUS OF THE CLEAR HILLS OF ALBERTA

G·L· COLBORNE
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SEDIMENTARY IRON IN THE CRETACEOUS
OF THE CLEAR HILLS AREA, ALBERTA

A DISSERTATION
SUBMITTED TO THE FACULTY OF GRADUATE STUDIES
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DEPARTMENT OF GEOLOGY
FACULTY OF ARTS AND SCIENCE
by
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Frontispiece

Aerial view from Notikewin forestry tower,
Clear Hills, Alberta. Looking northwest
to the Notikewin River.

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ABSTRACT

The wealth of oil and gas found in Alberta since 1947 has resulted in a greatly expanded economy. This has produced a growing market for iron and it's alloys in the western provinces, and has aroused the interest of several large international steel producers. Consequently all known occurrences of iron in Alberta have undergone investigation of varying intensity during the past few years.

This thesis sets forth the results of a study, from many approaches, of one of the more promising possible commercial deposits, located in the Clear Hills area of northwestern Alberta. This is a fine example of an oolitic iron deposit comparable, mineralogically, to many of the well known sedimentary deposits of iron throughout Europe and the United States of America.

The field and laboratory evidence appears to substantiate the assumption that the oolitic iron in the Clear Hills has definite commercial possibilities as a low grade iron ore. The prospective (but not proven) tonnage appears to be capable of supporting a large economical open pit operation.

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CHAPTER I

INTRODUCTION

General Statement

There has been considerable interest shown in low-grade iron occurrences in Alberta during the past four years. This interest, although blunted by the recessional period in 1957-58, still has sufficient promise to be kept alive for future investigation and development.

The iron occurrences in question range from a low-grade commercial deposit to mere traces in some sedimentary rocks. Geographically, the known occurrences are confined to the foothill belts of the Rockies and the Clear Hills of the Peace River district; geologically, they appear to be most prevalent in the Upper Cretaceous marine sediments.

The writer, under the sponsorship of Cliffs of Canada Ltd. (Canadian Exploration Company of Cleveland Cliffs, U.S.A.), was commissioned to examine all possible iron occurrences in the Province of Alberta, so far as time allowed during the summer of 1957. Several areas were visited but final emphasis was placed on the Clear Hills deposit.

The Clear Hills deposit presented the best commercial possibilities and a problem in diagenesis and environment of deposition. The Clear Hills deposit is of the oolitic type and probably comparable to similar deposits throughout the world. The writer will attempt to show this relationship along with possible determination of source area, age and environment of deposition.

The nature of oolitic iron of the Clear Hills area, both in grade and quantity, gives it priority over all other known occurrences in Alberta. The other areas examined will be treated briefly as a means of correlation with conditions of possible contemporaneous deposition.

Location of Areas and Accessibility

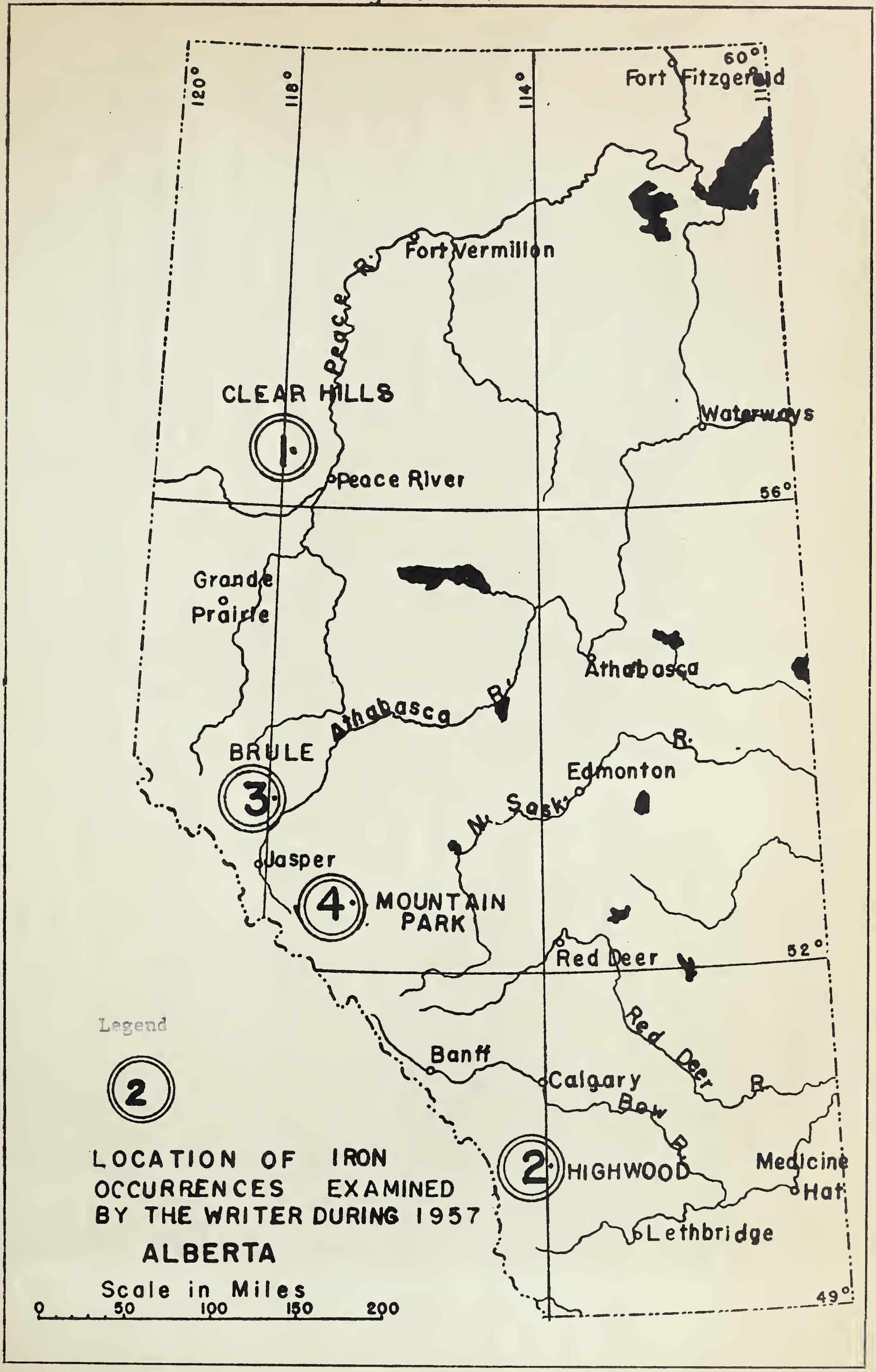
All the areas investigated are located in the Province of Alberta, and are accessible by roads of highway calibre at least to their perimeters. The locations themselves can be reached by Alberta Forestry roads. The areas are located on the index map of Alberta (Fig. 1, p. 3) and the following is a more detailed description of location of each area in order of decreasing importance.

1.	Clear Hills	Twps. 87, 88, 89, 90, 91, 92 Rges. 4, 5, 6, 7	W6
2.	Highwood River	Twp. 16 Rge. 5	W5
3.	Brule	Twps. 50, 51 Rge. 27	W5
4.	Mountain Park	Twps. 45, 46, 47 Rges. 22, 23	W5

The Clear Hills area on which emphasis is being placed is located 300 air miles northwest of Edmonton (Fig. 1, p. 3). The east and south boundaries are accessible by road and rail, by the Grimshaw highway on the east and Hines Creek, the railhead, on the south.

The area lies between meridians of longitude 118° 30' W and 119° 00' W, and is bounded on the north and south by parallels of

Figure - 1



LOCATION OF IRON OCCURRENCES EXAMINED BY THE WRITER DURING 1957

ALBERTA

57° 00' N and 56° 30' N respectively. This quadrangle includes all or parts of Townships 87 to 92 and Ranges 4 to 7 west of the sixth meridian (Fig. 2 in envelope on back cover).

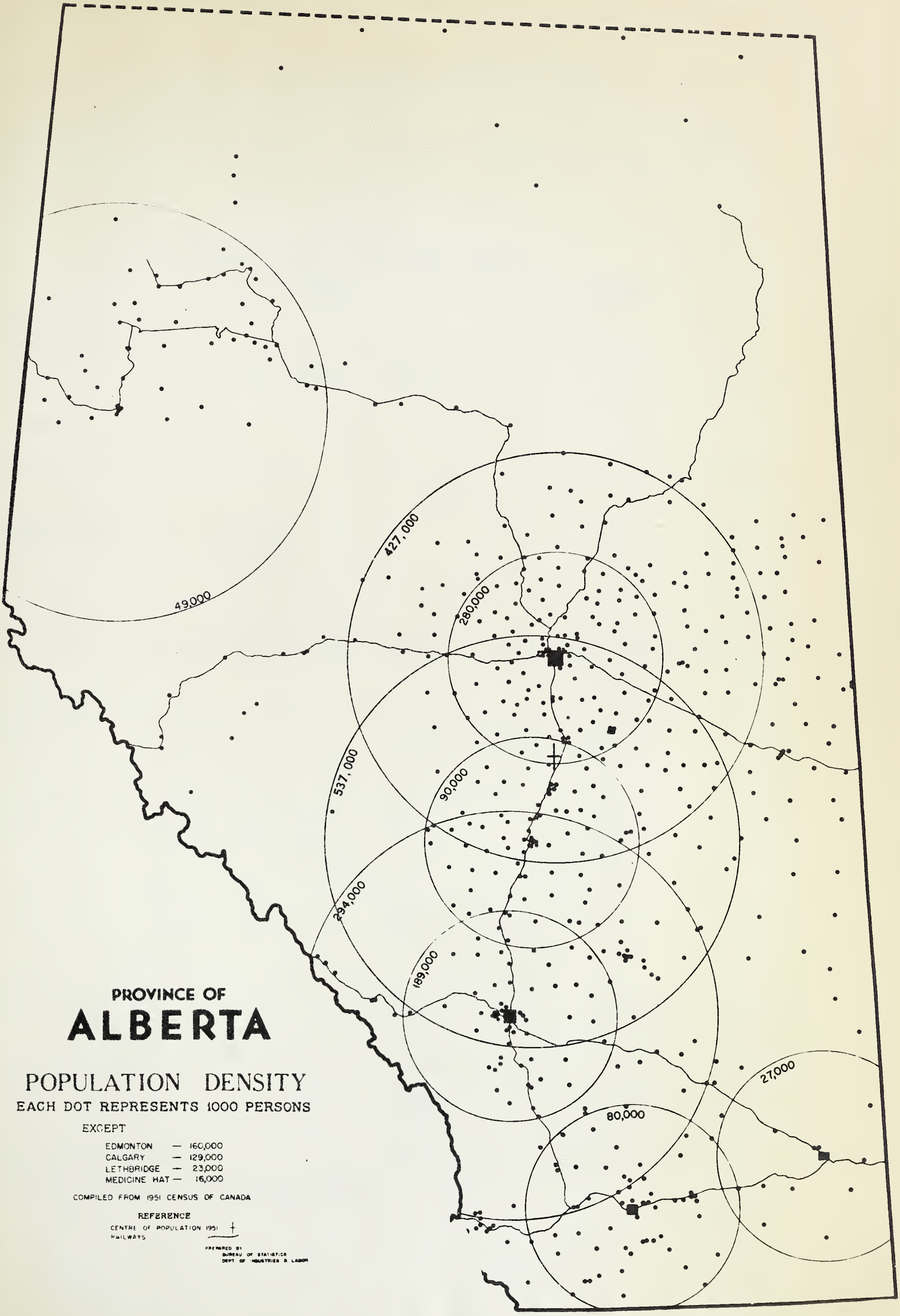
Culture

The chief occupations of the population in this area are similar to those of the entire Peace River Block - agriculture, subsidiary lumbering, and the usual winter trapping. The farming areas are confined to the perimeters of the Clear Hills and the remainder of the area in question is still a veritable wilderness, inhabited by a fairly large big-game population.

The area in recent years has been literally gridded with seismic exploration cut-lines and roads, which are only passable when the ground is frozen. The Clear Hills proper are devoid of human inhabitants, except for rangers of the Alberta Department of Lands and Forests during the "fire" season and trappers during the winter.

Economics is an important aspect of this thesis and it is therefore necessary to consider the population and density of population for the entire Peace River Block of Alberta. This would assume some importance as to local labor supply if and when a basic industry is developed. There are some 13 incorporated towns and villages in this area of approximately 34,000 square miles and the total population as shown by the 1951 census consisted of 54,102 persons (Table I, p. 6). At the time of the census this number was approximately 5.75 per cent of Alberta's total population (Istvanffy, 1954).

FIGURE 3.


PROVINCE OF
ALBERTA
POPULATION DENSITY
EACH DOT REPRESENTS 1000 PERSONS
EXCEPT
EDMONTON — 160,000
CALGARY — 129,000
LETHBRIDGE — 23,000
MEDICINE HAT — 16,000
COMPILED FROM 1951 CENSUS OF CANADA
REFERENCE
CENTRE OF POPULATION 1951
RAILWAYS
PREPARED BY
BUREAU OF STATISTICS
DEPT OF INDUSTRIES & LABOR
49,000
427,000
280,000
537,000
90,000
294,000
189,000
80,000
27,000

The rate of increase in Alberta's population (Table I) has accelerated since 1941. This is also an important factor in consideration of steel markets in the western provinces and should be related to density of population, as shown in Figure 3, page 5.

TABLE I

DENSITY OF POPULATION & AREA

	Area	Density
CENSUS DIV. 15	22,845 sq. miles	0.95
CENSUS DIV. 16	11,100 sq. miles	2.92
	33,945 sq. miles	

POPULATION (as of 1951)

Peace River Block, Alberta

Census Div. 15 -	21,663
Census Div. 16 -	32,439
	54,102

5.75% of Alberta's total in 1951.

Population of incorporated cities, towns, and villages as of 1951:

Beaverlodge	514	Fairview	929
Falher	575	Grande Prairie	2664
Grimshaw	564	High Prairie	1141
Hythe	342	Kinuso	238
McLennan	1074	Peace River	1672
Rycroft	372	Spirit River	553
Wembly	251		

Population Alberta	1941	796,169
Population Alberta	1951	939,501
Population Alberta	1953	1,002,000
Population Alberta	1957	1,200,000

Population increase 66% since 1941.

Present Work

The writer, employed by Cliffs of Canada, Ltd., under the direction of Dr. W.L.C.Greer in Port Arthur carried out field investigation of reported iron occurrences in Alberta during the field season of 1957, as complete as time would permit.

Sections of Cretaceous sediments with showings of iron were examined in the Highwood River, Mountain Park, Brule and Clear Hills areas (Fig. 1, p. 3).

Two areas showed some promise of grade and quantity: the Highwood area of southern Alberta and the Clear Hills area of northwestern Alberta. The emphasis was placed on the Clear Hills deposits and most of the detailed work in the field and laboratory was carried out on this material.

Samples were collected from all areas previously mentioned, with careful sampling of the two areas that were assessed to be actual prospective deposits. The Clear Hills and the Highwood River areas appeared to present the best possibilities. Thin sections of samples from exposures examined, including sections of the Clear Hills and Highwood samples, and key sections of samples from other areas of lesser importance to be used in possible correlation, were prepared by a commercial laboratory. Crushed mounts were also prepared from the Clear Hills samples. Complete quantitative analyses were carried out on the Clear Hills samples and sanidine feldspar was separated for A^{40}/K^{40} age determination. Further details of methods and results are described in their respective chapters.

Previous Work

The Peace River has been a historic trade route across this part of northwest Canada, and today the famous Alaska Highway passes through the area.

Earliest observations on the geology were generally confined to the banks of the Peace River and its tributaries. The generally open character of the country made it possible for some early explorers to carry out reconnaissance surveys overland.

The earliest report containing reference to the geology of the Peace River Block is that of Selwyn (1875-76) in a reconnaissance survey of areas in northeastern British Columbia and east along the Peace River. A later survey by Dawson (1879-80) covered the Peace River area in more detail. He subdivided the Cretaceous of this area and assigned formational names, some of which are still retained.

McLearn (1917-19) made a more systematic survey and study of the Cretaceous formations exposed along the Peace and Smoky Rivers.

A general report on the geology of the Mackenzie River basin (Camsell et al, 1919) contains a summary of the geology along the Peace and Smoky Rivers on a small scale map and in very little detail.

J.A. Allan examined the Cretaceous section along the Peace in 1921 and at some points along the Smoky River at a later date. The results of his observations appear in the Research Council of Alberta Reports for 1921 and 1924.

In 1929 a detailed survey of the geology and water resources was carried out in parts of the Peace River and Grande Prairie districts.

This report contained detailed descriptions of formations examined (Rutherford, 1940). Additional work was carried out by J.A. Allan and C.R. Stelck (1940) and again by C.R. Stelck (1941). These reports were concerned with the Pouce Coupe area but since there are formational correlations with the Peace River area they have been included as references. The advent of the province-wide oil and gas exploration was mainly responsible for the opening up of this particular area.

In 1951 Phillips Petroleum Co. Ltd. drilled a wildcat well in the Clear Hills area, located in Legal Subdivision 12, Section 29, Township 89, Range 4, west of the 6th principal meridian. The oolitic iron member was encountered after passing through 50 feet of glacial debris and 420 feet of the Kaskapau (Upper Cretaceous) formation. This was the first indication, to the best knowledge of the writer, that an oolitic iron bed of this thickness was present in the Cretaceous (Istvanffy, 1954).

In 1954 the Alberta Government issued four exploration permits covering iron occurrences in the Clear Hills area.

The McDougall-Segan Syndicate, formed in 1954, reported that diamond drilling of their deposit on the east flank of the Clear Hills in Townships 84 to 95, Ranges 3 to 6, west of the 6th meridian, had indicated a flat-lying bed of oolitic iron averaging 10 feet in thickness over an area 13 miles by 3 miles. A potential reserve of one billion tons of "ore" averaging about 34% iron was reported (Janes, 1957).

Concentration tests carried out by the Mines Branch, Ottawa, indicated certain problems. In 1956 the Research Council of Alberta

undertook research into the benefication of the iron, with special attention to mineralogy and chemistry of the deposit (Grace, 1956). A reconnaissance of the Clear Hills area made by Research Council geologists under the supervision of Dr. D.J. Kidd, during the summer of 1956, disclosed that the arenaceous oolitic iron of Upper Cretaceous age outcropped along the valley walls of Swift Creek in the Clear Hills. The outcrop area straddles the boundary between Townships 90 and 91, Range 3, west of the 6th meridian, and is roughly forty miles north of the railhead at Hines Creek. In July, 1956, Premier Steel Co. Ltd., Edmonton, took over iron permits that had been dropped by the McDougall-Segan Syndicate. During the fall of 1957 the writer carried out a field investigation of the Swift Creek areas.

CHAPTER II

GENERAL CHARACTER OF THE AREA

Geological Succession

The consolidated strata underlying the area shown on the map, Figure 2, are all of Cretaceous age. Only the oolitic iron member of the Kaskapau formation is exposed and forms the valley walls of some of the streams. The Dunvegan and older formations are exposed outside the immediate map area (Rutherford, 1930, p. 19), in the valley of the Peace River and near Grimshaw on the Mackenzie highway. A mantle of superficial Pleistocene and Recent deposits, varying in thickness from a few feet to approximately 100 feet, covers most of the area. The Pleistocene deposits are thickest in the preglacial valleys, where the continental ice sheet deposited most of its debris load. In general the strata dip to the south and regional slope, as indicated by the drainage, is to the north.

The general character of the formations in the area, names assigned to them and thicknesses as noted in the well log of Phillips "C" No. 1, are as follows:

TABLE - 2 -

TABLE OF FORMATIONS

Era	Period or epoch	Formations and thickness (feet)	Lithology
Cenozoic	Pleistocene	0-100 feet	Till; lake and stream deposits of boulders, gravel sand, silt and clay.
Mesozoic	Upper Cretaceous	Kaskapau 560 feet	Dark to black shales of marine deposition; some fine-grained sandstones and oolitic iron.
		Dunvegan 833 feet	Alternating sandstones and shales, brackish water deposition; some sandstones up to 50 feet thick.
		Shaftesbury 644 feet	Dark blue to grey friable marine shales; ironstone concretions.
	Lower Cretaceous	Peace River 251 feet	Massive sandstones, with a lower shale and alternating sandstone members.

Physiography

The Clear Hills area is part of the Great Plains region of western Canada. The area under discussion has been modified by glaciation and post-glacial laking (Pl. I, B., p. 85) from a maturely dissected topography to a youthful topography broken by the highland expression of the former uplands.

This area of low rolling hills, with a maximum elevation above sea level of approximately 3000 feet (local relief of 300 to 400 feet), lies on the northeastern edge of the Alberta syncline. Post-Cretaceous monadnocks are responsible for the hills, in pronounced contrast to the Eureka plain to the south. The surface expression is due mainly to accumulation of glacial debris in the form of end moraines and proglacial lacustrine deposits. The area appeared as a definite high during the Pleistocene and was probably responsible for the stagnation of the continental ice sheet in this area. The ice sheet contributed to the formation of many of the landforms present today.

Drainage

The waters of the entire Peace River area drain to the Arctic Ocean, by way of the Mackenzie River system.

The Clear Hills area is drained by streams flowing into the Peace River, which flows along the southern and eastern boundaries of the map sheet. The main streams flow across the area from west to east to the Peace River. Locally the drainage pattern is dendritic and youthful in stage.

The majority of the streams are underfit (too small to be responsible for the valley they flow in) and flow in glacial debris-choked preglacial valleys. The Notikewin River, largest in the area, forms the northern boundary of the area examined by the writer. It exhibits many splendid examples of ox-bow lakes, meander scars, meander scrolls and cyclic terraces. There is good evidence here of successive lowering of the meltwater during the final wasting of the continental ice sheet.

Some of the streams occupy proglacial spillways in part and preglacial valleys throughout the remainder of their course; while others have cut through the unconsolidated debris and are actively cutting the underlying Cretaceous bedrock. Summer rainfall ranges from 30 to 40 inches, consequently the dendritic drainage pattern in the unconsolidated glacial debris is very dense (Fig. 2). Springs are abundant on all slopes, indicating a very shallow water-table. The majority of springs carry iron in solution.

Preglacial Topography

Prior to glaciation this area is considered to have been a maturely dissected upland. The present topography has been modified to some extent by the erosive action of the continental ice sheet; the deep preglacial valleys have been filled with glacial debris and proglacial lacustrine deposits. The existing streams are presently eroding down to preglacial base level and are flowing in the same direction as preglacial streams.

The drainage pattern indicates a strong east-west lineation of ridges and hills. The hills are preglacial, modified by glacial action and masked with a veneer of glacial debris. Proglacial spillways have provided additional stream channels and are used in part by some of the present streams.

Terminal moraines in many localities occur on the preglacial ridges, restoring some of the relief that was destroyed by the continental ice sheet.

Forests and Woods

The uplands are the most heavily wooded (Pl. I, A., p. 85) and have not suffered fire damage in recent years. Spruce and poplar are most abundant and are sufficient in size and quantity to support several small lumber mills. There are several permanent planing mills in Hines Creek and many portable mills were noted, well into the map area. The stands of spruce would serve a mining operation's needs for timber.

The flat areas to the south, which include most of the settled districts, are in part open and in part wooded with poplar and shrubbery. This is gradually being removed as the cultivation of the land progresses.

It is also noted that spruce are found mainly on the north slopes and the aspen, poplar and birch groves are confined to the south. There appears to be very little mixing of coniferous and deciduous types. Forest reserves play an important part in the economy of this region.

CHAPTER III

DESCRIPTIVE GEOLOGY

Structure

The Clear Hills area is situated on the east limb of the "Alberta Syncline". Late Cretaceous and early Tertiary formations infilling the syncline are best developed in the southern half of Alberta. The distribution of these formations indicates that the trend of the synclinal axis is to the northwest. The axis extends northwest and crosses the Peace River near the west boundary of Alberta (Rutherford, 1930, p. 13).

Inclination of the strata forming the east limb of this syncline is generally small throughout the province. This holds true for the Clear Hills area, where the beds are flat-lying or dipping gently to the south.

The Clear Hills area has few outcrops. The only Upper Cretaceous bedrock examined in the field was the massive oolitic iron member of the Kaskapau formation. Any detailed study of structure from outcrop investigation is impractical. It is felt that the general structural features of the Peace River area as noted by previous workers (Rutherford, 1930, p. 14) holds for this area as well. Dips of low inclination to the south were observed in the oolitic iron member; but further evidence of structure was lacking. The overlying shales had been eroded off and underlying shales are not exposed.

Stratigraphy

The names assigned to the formations occurring within this area are tabulated in Chapter II. Most of these formations belong to the Upper Cretaceous. Correlation of these formations has been restricted to the Peace River and Athabasca River areas and is based on early work of McLearn (1917) and more recent microfaunal studies by C.R. Stelck and J.H. Wall (1954 and 1955).

None of the formations tabulated, with exception of the oolitic iron member, were examined in the field, but all were encountered in the discovery well. Descriptions of these formations are included in this thesis as a useful reference.

All of the formations described outcrop immediately outside the map-area. The following are detailed descriptions of the important formations of the Cretaceous of this area:

Peace River formation, Fort St. John group, Lower Cretaceous

Author: McConnell (1893)

Type locality: The Peace River sandstones ..... appear from beneath the latter (Shaftesbury formation) in descending the river immediately below the Smoky River forks, and are then exposed in the banks of the valley down to about three or four miles below Battle River (now Notikewin River).

Lithologic characteristics: McConnell - The Peace River sandstone consists of heavy massive beds of yellowish and greyish soft coarse sandstones, alternating with bands of thin-bedded sandstones and shales. The massive beds have an occasional thickness of fifty feet

or more, and weather into a series of steep cliffs separated by sloping terraces cut out of the shaly bands. Lignite seams occur occasionally, and hard sandstone concretions ranging from a few inches to ten to fifteen feet in diameter form a prominent feature of the formation. In descending Peace River, the Peace River sandstones become more argillaceous, decrease gradually in thickness and at length disappear a few miles below the mouth of Battle River. In 1951 Wickenden described the Peace River formation as consisting of the following:

Continental member
Cadotte member
Middle shale member
Basal member

In 1952 a study group of the A.S.P.G., under the chairmanship of L.E. Workman (1954), restricted the Peace River formation and redefined it so that it contained the following:

Paddy member - 0-130 feet, average 60
Cadotte member - 40-170 feet, average 70
Harmon member - 40-110 feet, average 60

Thickness and distribution: As redefined, the Peace River formation averages 190 feet in thickness and in the cross-section accompanying the A.S.P.G. study group report the formation is recognized in subsurface from the Alberta-British Columbia boundary eastward to the south shore of Lesser Slave Lake.

Relation to other units: The formation is underlain by the siltstones and sandstones of the Notikewin member of the Falher formation and is in

turn overlain by the dark marine shales of the Shaftesbury formation.

Shaftesbury formation, Fort St. John group, Lower Cretaceous

Author: McLearn and Henderson (1944)

Type locality: Lower Peace River, Alberta

History: The name "Fort St. John shale", originally used by Dawson (1880), applied to dark shales below the Dunvegan formation. Base defined by McConnell (1893) as shales between Peace River sandstones and Dunvegan formation. McLearn (1917) shortened name to "St. John" and used in the same manner as McConnell. Wickenden and Shaw (1943) raised Fort St. John to group status. McLearn and Henderson (1944) introduced Shaftesbury for shales formerly called Fort St. John and St. John in the lower Peace River area.

Lithologic characteristics: McLearn (1917) describes the formation as a sequence of dark blue to grey friable marine shales with occasional rounded or banded ironstone concretions.

Thickness and distribution: At type section 70 feet is exposed but it is estimated that at least 560 feet is present. In the Cache Creek area 1,300 feet has been measured.

Relation to other units: The contacts with the overlying Dunvegan formation and the underlying Peace River formation are conformable and gradational. The Shaftesbury is equivalent to the Cruiser, Goodrich, and Hasler formations of the Pine River area, British Columbia, and to lower Blackstone where the Dunvegan pinches out to the southeast. Wickenden and Shaw (1943) show a direct correlation with the "Dark Marine Shale" of the Lone Mountain area, British Columbia.

Paleontology: The Fish Scale zone is a prominent horizon within the Shaftesbury. The following fossils have been identified from the formation: Neogastroplites, Posidonomya nahwisi in British Columbia.

Dunvegan formation, Upper Cretaceous

Author: Dawson (1880)

Type locality: Near Dunvegan Trading Post, Peace River, northwestern Alberta

Lithologic characteristics: Consists of marine and non-marine sandstone, light grey to yellowish buff in color. Beds are massive and show crossbedding. Zones of thin-bedded sandstone and shale, shelly limestone and coal are present. Freshwater and marine fossils occur in the sands. The Dunvegan forms conspicuous light brown weathering mesas and buttes.

Thickness and distribution: 500' to 600' in the Peace River area thinning to the south and east. The Dunvegan extends from the Peace River area north to Fort Nelson and the Liard River, and in the foothills belt as far south as Jasper.

Relation to other units: The Dunvegan is overlain conformably by the Blackstone formation in central Alberta and by the Smoky River formation in the Peace River area of northeastern British Columbia. It is underlain by the Shaftesbury formation of the Fort St. John group. Both contacts are gradational. The Dunvegan is correlated with the Fort Nelson formation of northeastern British Columbia and the Liard River formation.

Paleontology: Non-marine fossils: Unio dowlingi; Melania; Unio

sulfuriensis; Corbula pyriformis var. dunveganensis.

Marine fossils: Corbula cf. nematophora; Inoceramus dunveganensis; Inoceramus mcconnelli; Inoceramus rutherfordi; Inoceramus athabaskensis; Barbatia micronema; Ostrea anomioides.

Kaskapau formation, Smoky River group, Upper Cretaceous

Author: McLearn (1926)

Type locality: On the Peace River, vicinity of Dunvegan, the base outcrops at the top of the Dunvegan cliffs. On the Smoky River below Puskwaskau River to about 12 miles below Racing Creek, this member is exposed on the valley sides.

History: The Smoky River group was first used by Dawson in 1879 for shale strata exposed on the Smoky River. This unit was subdivided in 1918 by McLearn into the following members: Upper Shale, Bad Heart sandstone and Lower Shale. In 1926 he assigned the name Kaskapau to the lower shale member. The name Kaskapau is apparently derived from the term "Ka-ska-pa-te-si-pi", Cree for Smoky River. Gleddie (1948) proposed formational status for the Kaskapau shale within the Smoky River group.

Lithologic characteristics: Predominantly dark grey fissile carbonaceous shale, friable near the base, with varying amounts of ironstone concretions throughout. Sandstone lenses occur near the top and thin fine-grained sandstone beds are found near the base.

Thickness and distribution: The Kaskapau formation is about 520 feet thick on the Smoky River, and about 550 feet thick in the Sturgeon Lake area. At Wembly the formation is either thickened by lenses or it interfingers with a late Dunvegan sandstone series. Warren and

Stelck (1940) include the Pouce Coupe sandstone in the Kaskapau formation.

Relation to other units: Succeeds the Dunvegan sandstone and precedes the Bad Heart sandstone. The corresponding unit of the central Plains occurs about 180 feet below the First White Specks to below the Second White Specks.

Pleistocene Deposits and Recent Deposits

Some reference to these deposits has already been made in Chapter II.

Pleistocene deposits, including those formed immediately following glaciation, are prevalent throughout most of the area.

The recent deposits, consisting chiefly of river gravels and sands, are of no special significance.

The deposits due to glaciation are chiefly derived from areas to the northeast, since ice from the Keewatin centre covered the area.

The Pleistocene deposits are two main types: unsorted materials derived from melting ice, boulder clays and gravels, and the semi-stratified glacio-lacustrine deposits of finer silt-like material (Pl. I, B., p. 85).

Lithology

This thesis is concerned with the study of the oolitic member of the Kaskapau formation. Therefore this section will deal with the lithology of the Kaskapau underlying and overlying the oolitic iron member.

The following well log of Phillips "C" No. 1, as described by Richard Procter (Procter first noticed the iron in the discovery well), gives a fairly detailed lithologic description of the bedrock encountered under the drift.

TABLE 3

LITHOLOGIC DESCRIPTION

Well log of Phil. "C" No. 1 - after Richard M. Procter.

Rock type	Description	Footage
Sand, gravel	Glacial drift	10-50
	Kaskapau formation	
Shale	light grey to grey-green, finely micaceous, slightly calcareous, bentonitic and silty. Lignite occurs as laminae in the shale.	50-120
Sandstone	light grey-brown, fine-grained. Sand grains in the rock are subrounded, well sorted, and mostly clear to pink quartz.	120-160
Sandstone with shale	Sandstone is generally shaly, and very calcareous at base of the section. Shale is grey to grey-buff, finely micaceous in part, and also slightly calcareous. The amount of the shale increases downward.	160-210
Shale	grey to light grey-green, fissile but soft, silty and bentonitic in part; small amounts of ironstone. Coal and sandstone are present in some places.	210-310
Sandstone with shale	shale is grey and yellowish brown, fissile but soft; bentonitic, silty and finely micaceous in part. Sandstone is buff to brown, fine-grained, quartzose, glauconitic, calcareous, carbonaceous, siliceous, and micaceous, and grading to argillaceous limestone in part.	310-400

Rock type	Description	Footage
Shale	grey, grey-green to buff; finely micaceous, bentonitic and silty in part. Pelecypod shell fragments are abundant. Sandstone beds are present in some places.	400-470
Iron-bearing oolitic bed	yellowish brown to red oolites are embedded in a dark brown to black matrix. The average size of oolites is less than 0.5 mm. in diameter. Some pyrite and bentonitic shale is present in various places.	470-610
Shale	grey, bentonitic, finely micaceous. Some pyrite and oolitic cavings are present in various horizons.	
	Top of Dunvegan formation.	

Age and correlation of the Kaskapau formation and its included oolitic iron member

The oolitic iron bed is associated with the shales and sandstones of the "lower" Kaskapau formation. Evidence elaborated below indicates the iron is upper Cenomanian in age. This places it in the lower portion of the *Gaudryina irenensis* microfaunal zone and the upper portion of the *Dunveganoceras* megafaunal zone and makes it approximately equivalent to the Doe Creek sandstone of the Pouce Coupe area. Stelck and Wall (1955, p. 20) outline a zonation based on foraminiferal faunistic changes from the upper part of the Cenomanian strata into lower Turonian stage as follows:

TABLE 4

FOSSIL ZONES IN THE KASKAPAU

Turonian	"Central" Kaskapau	Pelagic microfaunal zone (lower or second white speckled shale) *Haplophragmoides spiritense* zone (includes white chalcedony bed)
Cenomanian		*Ammobaculites pocalis* zone (includes Howard Creek sand)
	Lower Kaskapau	*Gaudryina irenensis* zone (includes Pouce Coupe sand at top and Doe Creek member near base) *Ammobaculites gravenori* zone
	Dunvegan restricted	Unnamed microfaunal zone

Stelck and Wall (1955, p. 7) presented a succession of lithologic markers from the lower Turonian to Cenomanian stage from the Pouce Coupe area (thicknesses are approximate).

TABLE 5

LITHOLOGIC HORIZON MARKERS

Formation		Members and markers
"Central" Kaskapau		Second white speckled shale member
		"White chalcedonic bed" or "white nodular member"
	50'	shale
		Cenomanian-Turonian contact
	20'	shale
		Howard Creek sand top
	130'	sandy and tuffaceous shales
"Lower" Kaskapau	30'	Pouce Coupe sandstone
	74'	shale with ironstone
	6'	Doe Creek sandstone
	190'	sandy shales

Dunvegan formation - sandstones and shales.

The terms "Central" and "Lower" were introduced by Stelck and Wall (1955, p. 7). Locally the "Central" and "Lower" Kaskapau portions have been correlated from Pouce Coupe to Spirit River (Stelck and Wall, 1954, pp.9-14). Regionally the Kaskapau has been correlated with many areas in the United States and Canada (Stelck and Wall, 1954, pp. 14-16).

A study of the microfaunal assemblages received from two core holes, Eureka No. 1 and No. 2 (McDougall, 1954) was carried out by Lenz (1956). The microfauna in the shales underlying the iron bed were found in both core holes, establishing a horizon for the iron bed.

Lenz (1956, p. 16) reported that all of the foraminifera were arenaceous forms and divided the fauna into two zones based on the *Ammobaculites gravenori* and *Gaudryina irenensis* of the Peace River area (Stelck and Wall, 1955, p. 21-22). Apparently neither of these species was present in this locality and Lenz (1956) based his zonation on the faunal assemblage and on the presence of *Proteomina alexanderi*. This placed the section in the Upper Cenomanian stage. Lenz (1956) concludes that the iron bed overlying the shales would be within the lower part of the *Gaudryina irenensis* zone. This would be equivalent to the Doe Creek sand (Stelck, personal communication), a thin sandstone member in the lower part of the Kaskapau formation of the Peace River area. Stelck and Wall (1955, p. 27) and Lenz (1956, p. 18) believe the environment to be near-shore, probably brackish or lagoonal, based on shallow-water arenaceous fauna present. Stelck and Wall (1955, p. 28) believe that the depth of water was slowly increasing, with a change from almost fresh water to normal salinity and with normal deposition from lowered source areas accompanied by the deepening of the late Cenomanian seas.

CHAPTER IV

GENERAL CHARACTER OF THE "ORE"

General Statement

The oolitic iron "ore" was examined in place, outcropping along the valley of Swift Creek (Fig. 2 - in envelope at back of thesis). The exposure varied in thickness at the surface from a few feet to over 25 feet. This variation was due mainly to slumping of superficial glacial deposits covering the outcrop wherever the angle of valley slope was low enough to support this material. The thickest sections were not examined in detail because the straight walls made them inaccessible (Pl. II, B., p. 86). However, the general character and appearance of the "ore" along several miles of the valley bottom was uniform and massive. There did not appear to be any variation so far as could be seen.

The only exception to this was the color change in the outcrop from water level up for several feet - the "ore" was definitely greyish green in color and graded into the brown and reddish brown. This variation in color can be seen in Plate VII, A., page 91; and Plate IV, A. and B., page 88. This color variation has definite chemical implications.

The oolitic iron weathers very easily because of its soft and friable nature. The well weathered surface takes on the appearance of a clay bank (Pl. III, A., p. 87) and could easily escape detection. Farther upstream the outcrop had been subjected to recent frost action

and fresh "ore" was exposed (Pl. V, A. and B., p. 89). In Plate III, B., page 87, close examination revealed a hint of weak bedding but the most noticeable feature was the large-scale polygonal pattern to the "ore", almost "honeycomb" in effect. This would seem to indicate post-depositional ground-water action with concentration of iron oxide along planes of weakness.

A typical exposure was chosen in excess of 24 feet and trenched to the fresh material (Pl. III, A., p. 87). This exposure was carefully measured and composite samples were taken from each two-foot interval. The exposure was sampled from the bottom up, since this was the simplest method.

Petrology

Megascopic description: DeFord and Waldschmidt (1946) presented the following definitions of oolite and oolith: ..... "An oolite is a rock made up of an aggregate of small spheroidal bodies called ooliths, held together by interstitial cementing material. The normal diameter of an oolith is less than one millimeter. The name oolith comes from the resemblance to fish roe .....". The recommended size range for the ooliths is 0.1 - 1.0 millimeters in diameter. The term ooid was recently proposed by P.E. Cloud (DeFord and Waldschmidt, 1946, p. 1588) to be used in preference to the term oolith by some authors to avoid confusion with oolite and oolitic. In this thesis the writer will use the terms oolite and oolith as elaborated by DeFord and Waldschmidt (1946).

The Clear Hills ferruginous oolite does not appear to have definite bedding planes. It is quite probable that if any existed they were destroyed by the post-depositional compaction of the material or by mechanical redeposition.

The oolite in outcrop and hand specimen presents a variety of colors ranging through grey-green (Pl. VII, A., p. 91), greenish grey, yellow-brown to reddish brown (Pl. VI, A., p. 90) with bluish black iron oxides concentrated along post-depositional fracture planes in the section. The oolite from a distance appears to be a rusty nodular sandstone. On closer inspection it is apparent that the material is sandsize but appears as uniform spheroids similar to very fine pellets, having a submetallic luster, embedded in an earthy matrix varying in color from greenish grey to reddish brown. Examination by hand lens and binocular microscope revealed fine sandsized angular quartz, false ooliths formed from rock fragments and irregular-shaped concretions of grey-green mudstone possibly chamositic or sideritic in composition.

The oolite exposure varied in hardness from the bottom of the exposure to the top. The softer friable material was found at the top of the bed. This may have been due to surface leaching and exposure but it was also noticed that the density of ooliths increased upwards and therefore the matrix volume decreased.

The oolite outcrop, where exposed to weathering for any length of time, disintegrated easily, presenting a yellowish brown earthy appearance (Pl. III, A., p. 87) which could easily be confused with

subsoil overburden. A portion of sample CH-10 (Appendix, p. 73) was subjected to several freeze-thaw cycles, having first been saturated with water. It disaggregated with facility and produced a very fine sand composed of the ooliths (Pl. VI, B., p. 90).

Samples from the upper beds, dark reddish brown in color, were extremely friable and could be broken up by squeezing between the fingers. Under the binocular microscope the material consisted largely of dark brown spherical, subspherical, and oblate spheroidal accretionary bodies displaying a submetallic luster, with common sizes less than 0.25 mm. The ooliths are loosely held in clay-like light greenish-colored matrix in the basal beds but as the percentage of ooliths becomes greater the matrix decreases and merely fills the interstices of the ooliths in contact.

Most of the broken ooliths exhibit fresh-looking angular quartz nuclei, concentrically surrounded by a dark brown limonite-like material. HCl (1:1 Soln̄) was applied on a polished surface of a sample and observed under the binocular microscope. It is noticed that an accelerated reaction takes place in or around the nuclei and sparsely in the matrix. It was found that the polished surface was extensively etched. The remains from the etching were quartz sands and concentric rings of limonite-like material.

The surface exposures of the oolite present a definite nodular appearance (Pl. III, B., p. 87); and (Pl. IV, A., p. 88) and in fact individual nodules are quite common. Fossil wood (Pl. VII, B., p. 91) and bone were discovered in the oolitic iron bed and identified as such by C.R. Stelck (personal communication).

Microscopic description: Two series of thin sections were prepared and examined. This included 16 from the Clear Hills samples and 15 from the Highwood samples (Appendix, pp. 77-78). The Highwood thin sections were included for possible correlation of environment of deposition, source material and source area. Since variation in the material of the Clear Hills oolite was not great a general description is given, supplemented by mention of particular features characteristic of certain horizons. Outstanding examples of diagnostic features and mineralogy are depicted in the color plates included in this thesis.

The soft nature of the oolite prevented the production of thin sections of standard thickness. This was a disadvantage in that it was impractical to obtain optic figures or use birefringence in most cases in determining the minerals present. This was overcome to some extent by correlating results of other chemical and physical tests, to arrive at a reasonable determination of the mineral character of the oolite.

Because of the thickness of the thin sections it was necessary to utilize maximum light with the aid of the converging lens and without use of the analyser nicol.

The basal beds of the exposure, greyish green in the hand specimen (Pl. IX, A., p. 93), under the microscope appeared as a mass of uniform-sized spherulites or rhombs of grey-green siderite with the occasional fragment of clean angular quartz. The ooliths were a minor constituent, probably less than 10 per cent.

Nodules removed from the deposit indicated the possibility

of erosion and redeposition of the primary oolite. These nodules appeared to be composed of a microcrystalline sideritic (chamositic?) mudstone, with included individual ooliths and rock fragments containing ooliths (Pl. VIII, A. and B., p. 92). Fossil wood (Pl. XI, A. and B., p. 95) and bone is liberally distributed throughout the exposure and is indicative of near-shore environment.

The character of the oolite changes rapidly upward in the exposure. The color change is due to increase in the percentage of ooliths (Pl. VI, A., p. 90) and the increase in the amount of limonite-goethite present in the shells of the ooliths.

The ooliths show little evidence of distortion through compaction and the variable shapes can be related to the odd shapes of the nuclei (Pl. IX, B., p. 93 and Pl. XII, B., p. 96).

The ooliths vary in arrangement from being "suspended" in the matrix in the basal beds to being very closely packed. At points of contact there is little if any indentation. There are two possible reasons for this: either the ooliths were deposited in an indurated state or the matrix was soft and acted as a cushion until they were sufficiently indurated.

The nuclei of the ooliths consist of a variety of media (Pl. IX, B., p. 93). The clear subangular grains of quartz are by far the most abundant. In most cases the quartz is clear and unchanged but examples of replacement are not uncommon (Pl. X, B., p. 94). Nuclei of the ooliths consist of the following: quartz, from 15 to 40 per cent, fragments of ironstone nodules, rock fragments, and subrounded feldspar grains (orthoclase clear and fresh). No fossil

foraminifera appear to be present in any of the thin sections examined. The total volume of the ooliths in the section examined varies from 10 per cent at the base to over 50 per cent in the upper beds.

The matrix is composed of the same minerals found in the ooliths: siderite, chamosite (glauconite?), limonite-goethite after siderite, quartz, feldspar, rock fragments, with the occurrence in some samples of secondary calcite, and chert fragments. In thin section No. 3080 there is evidence of chalcedonic replacement of calcite. Plate XIII, A., page 97 presents a good example of secondary calcite probably replacing siderite; all vestiges of concentric oolith structure have been destroyed.

Sideritic-chamositic (glauconitic?) mudstone forms the major portion of the matrix and varies from 10 to 50 per cent of the total volume of matrix. It varies in color from a dirty greyish green yellowish green to dirty brown, poorly translucent and is in thin section characteristically splotchy and non-uniform. Absolute determination of chamosite in the matrix was not possible. The siderite exhibits a spherulitic texture and occasionally shows good rhombic form (Pl. IX, A., p. 93).

Within the matrix are loose angular grains of quartz, occasional grains of clear subangular feldspar (commonly orthoclase), pseudo-ooliths formed of rounded fragments of ironstone and fragments of wood and bone (Pl. XI, A., and B., p. 95).

Chemistry

Quantitative chemical analyses were carried out on a series of 12 oolitic iron samples, CH to CH-12 inclusive (Appendix, p. 73).

This work was supervised by H. Baadsgaard and the analytical work done by G.M. Hughes and the writer. This analytical work was primarily carried out to determine the per cent weight of ferrous iron and ferric iron in the Clear Hills oolitic iron. The results were used to advantage in substantiating the presence of siderite ($FeCO_3$) in this deposit. One complete analysis was carried out at the University by C.E. Noble, Provincial Analyst, one by Cliffs of Canada Ltd. (p. 36) and several by the Research Council of Alberta for McDougall (1954) (Appendix, p. 76).

The iron in the basal beds is almost completely ferrous iron. This corroborates the large percentage of siderite determined in the thin sections as occurring in the lower beds. The ferrous iron content decreased from the base upwards, in the uppermost sample it is in negligible amounts.

The complete analysis revealed minor amounts of calcium oxide, magnesium oxide, and manganese. Sulphur occurred in a few samples; the sulphur may have been released by the decomposition of pyrite. Pyrite was present in small amounts as microgranular crystals in the basal beds. Calcium, sodium, minor amounts of tin and possibly chromium were found in the McDougall samples in a spectrographic analysis (Appendix, p. 76).

The complete analysis also indicates that there is sufficient silica, alumina, magnesia and phosphorus present to account for the presence of chamosite.

The chemical analysis has confirmed identifications which

had been made by petrographic methods and established the presence of other minerals not indicated by microscopic examination.

The petrographic and chemical examinations indicate the presence of three principal iron-bearing minerals which include a complex oxide, a silicate and a carbonate. Shell matter probably accounts for the phosphorus content, the minor amounts of magnesia and lime indicated by the analysis, and some of the secondary calcite as revealed by petrographic examinations.

The ore and accompanying rocks appear to be free from any original lime content outside the small amounts indicated by the complete analysis.

All of the constituents of the "ore" vary somewhat from layer to layer and a representative mineral assemblage with limiting percentages is as follows:

Limonite-goethite ($2Fe_2O_3.3H_2O$ - $Fe_2O_3.H_2O$)	5-25%
Siderite ($FeCO_3$)	5-25%
Chamosite $15(Fe,Mg)O.5Al_2O_3.11SiO_2.16H_2O$	5-10%
Quartz (SiO_2)	15-20%
Collophanite? ($Ca_3P_2O_8$)	1-2%
Orthoclase ($KAlSi_3O_8$)	3-5%
Pyrite (FeS_2)	0-1%
Carbonaceous matter (C)	0-5%

Chemically the average sample from the middle of the deposit is approximately as follows:

Iron	30.15%
Silica	25.36%
Alumina	6.24%
Sulphur	0.70%
Phosphorus	0.58%
Manganese	0.15%

(The above analysis was run by Cleveland Cliffs Ltd., Ishpeming, Michigan, in core from Phillips "Can" No. 1).

Geochronology

Age dating was undertaken to establish an age for the oolitic iron in the Kaskapau formation. The presence of sanidine feldspar, presumably of volcanic origin, provided an opportunity to obtain an age by the potassium-argon method.

Sample: A composite sample, collected from location "A" on Swift Creek (Fig. 2), representing the 16-foot to 28-foot interval (depths from surface on exposure) was used in the determination.

Preparation of sample: The composite sample of oolitic iron "ore" was mechanically crushed and pulverized. The disaggregated sample was put through a series of sieves consisting of the following screen sizes: 35, 60, 80, 100, 140, and 200 meshes to the inch (U.S. Sieve Series). The sample retained on the 140 mesh appeared to present the best size. The sieving was carried out twice, once wet and once dry.

The sample was then separated into light and heavy fractions using heavy liquid tetrabromoethane (sp. gr. was reduced to 2.54 by addition of acetone and checked with feldspar chip at 20° C). The light fraction was then run through the Frantz magnetic separator at all amperage settings and two final passes at maximum of 1.5 amps. The material in the non-magnetic fraction was then subjected to further heavy liquid separation, using tetrabromoethane (at specific gravity 2.54) and the light fraction with specific gravity less than 2.54 obtained from this operation amounted to about 6 grams. The sample appeared to be mainly feldspar with some quartz contamination.

A mount of the material was made up in Canada Balsam. This mount was examined under the petrographic microscope. The writer concluded that the feldspar present was mainly sanidine.

Potassium-Argon method: This sample was run by H. Baadsgaard after a series of washings with HCl to remove all traces of iron. The following information was obtained:

AK No. 14	Slide No. 3224
K mineral	Sanidine (?)
Oolitic member	Kaskapau formation (Upper Cretaceous)
Run No. 13	A^{40}/gm. sample 1.53×10^{-5} cc. STP
% K_2O - 2.63 (F-23)	$A^{40}/K^{40} = 0.0103$
%K - 2.18	Calculated age = 169×10^6 years.

Conclusions: It is quite apparent that the sanidine does not date the time of deposition of the iron. Feldspar in the matrix is detrital; it could possibly provide some indication of the source material.

The age places the sanidine formation in Jurassic, at about the time of the Topley batholith. Detritus from the erosion of this intrusive might possibly be the source of the iron and its associated detrital material.

Conditions of Deposition of the Iron

Castano and Garrels (1950, p. 770) based on their "experimental sea" reported that rivers of moderately low pH draining into the sea might well contain considerable quantities of ferrous iron. It has been shown that river water pH varies considerably, but some river waters have values of 7.0 or lower (Rankama and Sahama, 1950, p. 228). On reaching the sea the river would drop its clastic load. If the river entered an area of open circulation the iron would probably be precipitated immediately and be diluted with the clastic material. If, however, the area of deposition was a lagoonal or restricted basin type, the river waters would very likely keep the lagoon or basin waters fairly fresh or at most brackish. If this were the case the clastics would be left behind and the iron carried to a place where there was sufficient ocean water in equilibrium with calcium carbonate to oxidize and precipitate the iron. In sediments and sedimentary rocks ferric iron precipitates as the common valence state.

As a general rule, siderite rarely occurs in ores. It must depend for its formation on the activity of the ferrous ion and the activity of the carbonate ion. Conditions for $FeCO_3$ formation would

be fairly high pH, where ferrous ion activity is maximum and the hydroxyl ion is relatively low. Both hydroxyl and carbonate increase with increasing pH and ferric iron predominates.

Where organic debris such as has been found in the Clear Hills oolite and stagnant water coexist, oxygen is rapidly removed. Iron moving into such an environment might be expected to precipitate as ferrous compounds. Therefore, formation of siderite and chamosite would be expected.

It can be stated that iron-bearing solutions moving into aerated ocean waters containing calcium carbonate will precipitate ferric oxide (Rankama and Sahama, 1950, p. 666). With the addition of silt and slight lowering of pH, chamosite might possibly be formed. If, however, iron-bearing solutions move into an area of stagnant water where organic debris tends to accumulate, the minerals formed might well be chamosite (if silt present) or siderite and pyrite.

Such conditions would not be expected to last very long; movements of the strand line might well put a given basin beyond the range of iron, and calcium carbonate deposition might be resumed. A change in river volume or silting up of a clastic-trapping basin might result in the common precipitation of the iron along with the clastic deposition. This appears to be the case at the time of iron deposition in the Clear Hills area. The thickness of the iron bed does not exceed 30 feet (McDougall, 1954) and is on the average approximately 15 feet. This would indicate a relatively short period of deposition. The environmental pH varied from time to time

due to alternating periods of deposition of organic material, stagnant water conditions, and periodic re-entrance of normal sea water.

The ferrous to ferric iron ratio decreases from the base of the examined section and the upper beds contain only minor amounts of siderite and chamosite. There is sufficient Al_2O_3 present to account for the presence of chamosite or chamositic mudstone.

Chamosite (hydrated Fe, Mg, Al, Silicate), known to form only in a marine environment, may be a secondary replacement of quartz and feldspar, and probably forms when the basin of deposition is subjected to an inflow of silt carried by the streams.

Ferrous bicarbonate may be formed by the action of CO_2-bearing waters on ferrous minerals in the absence of oxygen. The supposition that iron is carried in solution, principally as the bicarbonate or soluble carbonate, is fairly well founded (Harden, 1919, pp. 64-84). Iron will remain in solution if CO_2 is in excess; when CO_2 is decreased precipitation results. If oxygen is present in normal amounts ferric hydroxide will be precipitated and if oxygen is scarce ferrous carbonate will come out of solution.

In areas of brackish water in marine swamps and marshes iron is deposited in the presence of plants. Decaying vegetation inhibits oxidation as stated above, and iron is deposited as ferrous carbonate. Even if ferric hydroxide were precipitated, it could be reduced and the formation of ferrous carbonate could take place.

The aforementioned environment is very similar to that favoring coal accumulation and presence of carbonaceous material

would indicate that conditions were almost right for this to occur as well. In many parts of the world siderite is associated with coal.

Low gradient sluggish streams have a very low suspended load capacity. The major iron load of this type of stream is in solution as a bicarbonate or a ferric colloid. This would account for the lack of common sediments mixed with the iron. If these streams debouched into brackish waters having an above normal content of humic acid, the ferric compounds might be reduced to the ferrous state and deposited as carbonate. The occurrence of brackish water microfaunas in the underlying shales substantiates the belief that the zone of deposition was a lagoon, a barred basin, or an estuarine delta area.

Formation and Deposition of Ooliths

The writer believes that the Clear Hills deposit is comparable to Wabana iron ore of Newfoundland in some aspects. Hayes (1915, p. 93) notes a total lack of limestone or igneous rock in the Ordovician series of sedimentary rocks of Newfoundland. This also applies to the iron member of the Kaskapau formation and the underlying and overlying Cretaceous sediments. The phosphate indicated in the analysis on page 37 could very well be derived from fossil shell remains. There is no evidence that transformation from an original oolitic limestone to oolitic siderite-limonite has taken place.

Hayes (1915, p. 82) also contends that the siderite of Wabana formed at the sea bottom or just below the surface of deposition at the expense of chamosite and hematite in the presence of organic debris undergoing decomposition. Hayes finds siderite at the base of the Newfoundland bed, a noteworthy comparison since the siderite of the Clear Hills oolite is most abundant at the base of the bed and decreases upwards. It has been shown that it tends to replace quartz and limonite-goethite.

The formation of Florida and Bahama oolites is said to be dependent on bacteria active in shoal waters precipitating enormous quantities of calcium carbonate (Illing, 1954, p. 41) under definite temperature conditions and salinity. The chemically precipitated calcite may form spherulites which in turn form ooliths by accretion aided by wave action in the shallows. Similar physical methods might have been operative for the formation of the siderite-chamosite-limonite-goethite ooliths.

Krumbein and Garrels (1952, p. 28) believe that siderite precipitation takes place in barred basins or stagnant lagoons or estuaries at a pH of 7.0 to 7.8 and an Eh of approximately -0.2.

The writer believes that the Clear Hills ooliths are primary in origin, because of the following observations:

(1) There is no evidence of primary calcite ooliths

(2) In near-shore marine waters the redox potential and pH tend to favor the formation of siderite

(3) There are no limestones of note in the Cretaceous

lithologic sequence involved, and least of all oolitic limestones

(4) The siderite is for the most part amorphous and there is little evidence of secondary crystallization

(5) The carbonate content of the waters of deposition was not in excess or limestone would have been precipitated

(6) The carrier water would have to be carbonated to carry sufficient iron to account for the deposit

(7) The carbonated iron-bearing fresh waters, on reaching the marine or brackish water of higher pH, would tend to precipitate iron out as a carbonate.

That the formation of ooliths is due to precipitation caused by physio-chemical reactions has been conclusively established (Bucher, 1918). The environment of oolith deposition was a controversial subject for many years. Hayes, Gruner, Illing, Kelly and many others working in this field have concluded that ooliths are formed in relatively shallow water of estuaries, lagoons or very shallow seas, where the turbulent action of current or waves served to suspend suitable nuclei for subsequent accretion of oolith shells. This concept is now generally accepted.

Oolitic iron deposits are almost entirely within marine beds but it has been reported (Kelly, 1951, p. 2222) that ferruginous ooliths are now forming in certain Swedish lakes. It is also known (Twenhofel, 1939, p. 573) that oolites form under subaerial conditions in certain soils and of course these oolites might be eroded and deposited in the sea. Furthermore, it has been recognized that oolites

formed one place in the sea probably have been reworked by currents and deposited in their final burial place wholly by mechanical means. There is considerable evidence to support the theory that this is the case with the Clear Hills oolitic iron deposit. There do not appear to be any gradations in the Kaskapau, contacts are sharp chemically, lithologically, and faunal-wise. Nodules (Pl. VIII, A. and B., p. 92) are common in the deposit containing a mixture of sideritic chamositic matrix, individual ooliths and rock fragments with included ooliths. Oolith fragments are not uncommon, together with fragments of chert, secondary calcite after ooliths (Pl. XIII, A., p. 97), calcite veins, pseudo-ooliths of rounded rock fragments (Bastin, 1950, p. 67) and ironstone nodule fragments. Lack of fossils of marine origin in the deposit also points to possible mechanical deposition of the primary material.

Iron mineral oolites may develop by either: (1) accretionary growth about a nucleus before burial (Pl. XII, A., p. 96); (2) concretionary crystallization from a hydrogel of amorphous solid; (3) pseudomorphous replacement in sea water of an earlier non-iron oolite (Brown, 1914, p. 770); (4) oolitic replacement in sea water of a non-oolitic substance; (5) crystallization in oolitic form of finely divided crystals and amorphous materials after burial; and (6) replacement by salts in pore-space (connate) water after burial.

The writer believes that the Clear Hills oolite falls into the first division of the above summary of types of oolitic development.

Despite the various ways that deposits of iron can be formed it would appear from the findings of Moore and Maynard (1929, p. 301) that the dominant manner of deposition of iron minerals is by coagulation of hydrosols and hardening of hydrogels.

Source of the "Ore"

Van Hise and Leith (1911, p. 499) concluded that all the important Lake Superior iron-bearing formations are similar in origin. They believe that a very large part of the iron and silica was contributed to the ocean directly, either by magmatic emanations from igneous rocks in the ocean floor or rapid decomposition of basic igneous rocks in contact with sea water while still very hot. This theory was expanded by Collins, Quirke and Thomson (1926, pp. 1-141) and by many others working in this field.

The average river water today contains less than one part per million of iron (Gruner, 1922, p. 421). This suggests that these waters are inadequate as a source for the deposition of iron formation as defined by James (1954, p. 239). James defined iron-formation as follows: ..... "a chemical sediment typically thin-bedded or laminated, containing 15 per cent or more iron of sedimentary origin, commonly but not necessarily containing layers of chert". Rivers in tropical climates such as the Amazon of Brazil, however, carry 2 to 7 parts per million of Fe_2O_3. Van Hise and Leith based their work on studies of temperate weathering cycles. James (1954, p. 276) points out that vulcanism, though not uncommon during periods of

iron deposition, is not necessary or always contemporaneous.

It has been established that the Clear Hills oolith is a sedimentary formation. There has been no evidence that vulcanism played any part in supplying source material. It appears that the environment of deposition resembles that of the Lake Superior region (James, 1954, p. 280), with the exception that there was apparently no tectonic activity associated with the period of deposition. Iron is a common component in the Cretaceous sediments of all ages and often forms enriched zones of nodules or replacement beds such as in the Blackstone-Cardium zone in the Highwood area (Pl. XV, B., p. 99, and Pl. XVI, B., p. 100).

The analysis of the Highwood samples (Appendix, p. 78) indicates that the iron content can be substantial. Therefore it does not seem unlikely that the Clear Hills oolite could be deposited during periods of optimum conditions. The original material appears to have come from a western granitic source, as indicated by the fresh quartz and feldspar, both transport resistant, and only the odd fragment of chert. The intrusion of the Topley granite and related intrusions in Jurassic time, subsequent deep weathering under tropical conditions, and alternating wet and dry seasons provided a low lying source area and sluggish rivers (Alling, 1947, p. 1011) to transport iron in solution to the lagoons or estuaries marginal to the Kaskapau sea.

Occurrences of Similar Ore

Clinton iron ore beds: The Clinton iron ore beds rank next in importance to the Lake Superior deposits (Bateman, 1942, p. 568). These beds outcrop across Wisconsin and New York and south to Alabama.

The ore occurs as sedimentary beds intercalated with shale, limestone, and sandstone of Clinton (Silurian) age. The types of ore are: (1) oolitic ore composed of round oolites of hematite, 1 to 2 mm. in diameter, enclosed in a matrix of hematite and calcite; (2) fossil fragments partly replaced by limonite and enclosed in amorphous oolitic hematite; (3) flaxseed ore composed of flattened concretions of hematite surrounded by hematite mud and replaced fossil fragments. Alling (1947, p. 1015) believes the Clinton ores to be primary due to the diagenesis of marine limestones in the presence of solutions well supplied with iron compounds. He also believes that the original iron compounds could have been ferrous and have become oxidized to the ferric state.

Wabana iron ores of Newfoundland: The oolitic iron ore with ferruginous shales and sandstones forms part of a series of sedimentary rocks of lower Ordovician age. Siderite occurs in smaller quantity than chamosite or hematite but is locally abundant. It replaces hematite and chamosite and in some instances detrital quartz. The siderite was chemically precipitated according to Hayes (1915, p. 93), probably under the cover of overlying sediments. This could also be the case with the Clear Hills ore deposit. Hayes also believes (1915, p. 94) that the Wabana iron ore is primary and is mined today in essentially

the same conditions as deposited, except for induration, faulting, and minor additions of secondary calcite and quartz.

Minette ores of Luxemburg and Lorraine: These ore deposits resemble the Wabana ores in their oolitic character and the content of green ferrous silicate. It is believed that they were deposited on the bottom of a shallow coastal sea. Formerly these deposits and many similar deposits were considered to be metasomatic replacements of limestones. The primary character of the deposition is now fully recognized (Tyrrell, 1937, p. 230).

Oolitic ores of Bohemia and Thuringia, Germany: Oolitic hematite-chamosite-siderite ores occur in these regions of Germany in rocks of lower Silurian age. This ore also resembles the Wabana deposit. The fact that limestone is entirely lacking in this lithologic sequence is noteworthy.

Cleveland iron ores of England: The most important ores of England, the Jurassic ores of the Cleveland Hills in North Yorkshire, are comprehensively reviewed by Bastin (1950, p. 69) in a summary of the work of A.F. Hallimond (1925, p. 10) in a paper written for the Geological Society of Great Britain. These deposits are characteristically oolitic and all evidence points to them as being primary in nature. They differ from most other oolitic iron ores in that the iron is largely in a ferrous state as chamosite and siderite. Ferric oxides are rare and if present occur as products of recent weathering. In the Cleveland ores the ooliths average about one-sixteenth of an inch in diameter and are composed of chamosite and siderite. The

chamosite is fine-grained and concentrically banded. Siderite is granular and usually replacing chamosite. Some ooliths are wholly chamosite but rarely wholly siderite. Many ooliths have no recognizable nucleus but others contain shell or oolith fragments. The matrix consists of siderite rhombs in a groundmass of fine chamosite. The Cleveland oolitic iron ore appears to bear a close resemblance to the Clear Hills oolitic iron "ore" in structural and mineralogical characteristics.

CHAPTER V

ECONOMIC GEOLOGY

General Statement

The oolitic iron "ore" may have a significant place in the future development of the province of Alberta. The deposits do not approach the "Mesabi type" in grade and purity but past history has shown that man can make good use of the material at his disposal. Therefore it is necessary that a summary of the pertinent features of the economic background of the province be presented. It will be seen that all of these factors are interdependent and probably hold the key to the development of this low grade iron.

The Clear Hills area is located within the area designated as the "Canadian North Pacific" (Camsell et al, 1947). This area was so named for study purposes by the Canadian section of the North Pacific Planning Project, headed by Charles Camsell, and initiated in 1943. The main purpose of this project was defense study of the northern areas of North America but the analysts also produced a report on the future economic possibilities of this vast region.

The region comprises approximately 1,000,000 square miles, more than one-quarter the area of Canada. Prior to World War II there were less than 1000 miles of usable roads in the entire area. The Peace River district, which includes the Clear Hills, was the

only part of this region that had a sizable population and transportation facilities.

Land Transportation

Hines Creek is located at the end of steel, on the edge of the iron deposits. The Northern Alberta Railroad reached this trading centre in 1930. The area is accessible by two all-weather highways of the Alberta Highway System, to Hines Creek on the south and the eastern boundary is readily accessible by way of the Mackenzie Highway, which begins at Grimshaw, a few miles west of the town of Peace River. There is a possibility of the road to Hines Creek being extended westward by direct route to Fort St. John in British Columbia, where the Pacific Great Eastern Railway has recently been extended, providing the Peace River district with an outlet to the Pacific coast. Forestry Department roads and oil-company exploration trails and roads make practically all parts of the area open to travel at various times of the year, dependent on seasonal conditions.

Agriculture

Hines Creek is an important trading centre, in the heart of a rich mixed farming and lumbering district. The area was originally ranching country, supporting thousands of sheep and cattle. Ranching has been superseded but not replaced by one of the best mixed farming areas in the north. Hines Creek is a trading centre for about 4,000 settlers from the surrounding area. Hundreds of carloads of cattle,

sheep, hogs and dairy products are shipped from this centre each year. Forecasts of the settling of 1,000,000 acres of 3,000,000 acres available have been made for the very near future.

Forests

Only rough estimates of the timber resources of northern Alberta lying within the North Pacific region are possible. The northern portion of the province, lying between the 55th parallel of latitude and the northern boundary and between 114th and 120th meridians, has been estimated to contain about five and one-half billion board feet of merchantable timber (Camsell etal, 1947, p. 55-57). This figure considers the conifers only and since the Forestry Department of Alberta believes that the poplar and birch growth is probably three times greater it can easily be seen that the timber reserve is spectacular.

Considering the Clear Hills area as a unit, estimates of 790 million board feet of timber have been given. During 1957 Hines Creek planing mills shipped more than 26 million board feet. In addition to this production approximately 60 carloads of pulpwood are shipped annually from this centre.

Water-Power Resources

The Peace River drains an area of 119,000 square miles and is the largest tributary of the Mackenzie drainage system. The headwaters are located in a great intermontane valley, west of the main

range of the Rocky Mountains. One half of the drainage area is in the Cordilleran region and the remainder forms part of the Great Central Plain. The Peace River is navigable by river-type steamers from its mouth to Hudson Hope in British Columbia, apart from the obstruction at Vermilion Chutes.

Water supply: The flow of the Peace River varies considerably because of the distinct physiographic divisions in its drainage basin. The greater part of the run-off comes from the mountain section dependent on temperature and precipitation. The records at Peace River town show a maximum discharge of 375,000 c.f.s. in June, 1922, and minimum discharge of 6,350 c.f.s. in December, 1916. The average annual flow is approximately 62,000 c.f.s. (Camsell et al, 1947, p. 77).

Power resources: No power development had been made in the Peace River basin prior to 1947. Studies for development on the Nation River, for supply at Pinchi Lake, were being made at this time. Several possible power sites have been investigated on the Peace River, with estimated potential horsepower available ranging from 25,000 to 500,000.

Power possibilities are indicated on a number of the tributaries of the Peace but information is insufficient to give any estimates of their potentialities. The power sites appear to be available but large power-consuming industries would be required to warrant their development. The province of Alberta in its entirety has a potential of only 2.5 million kilowatts of hydro-electric power on all of its rivers. Therefore power resources in British

Columbia adjacent to this area must be considered.

Mineral Resources

The Clear Hills area, underlain by sediments, does not offer any possibility for metallic mineral deposits, apart from the oolitic iron occurrences. Non-metallics and hydrocarbons are of great importance in the Peace River district of Alberta and British Columbia.

Coal: The coal deposits of the Peace River district (British Columbia) are among the most important undeveloped coal reserves in the west. They are known to occur over an area of several thousand square miles. A recent compilation of mineable coal reserves has placed these at over one billion short tons (Camsell, 1947, p. 35). The coal available would provide the economic fuel required for the smelting of the iron "ore".

Peace River district, Alberta: The coals of Alberta are classified according to the classification of coals by Rank A.S.T.M., Designation D388-38. Allan (1943, p. 166) reported that there was no anthracite coal or lignite, with the exception of one seam in the Pakowki area. In the Peace River area of Alberta three general coal areas have been located (Fig. 4, p. 57) where coal has either been discovered or produced (Allan, 1943, p. 167).

TABLE 6

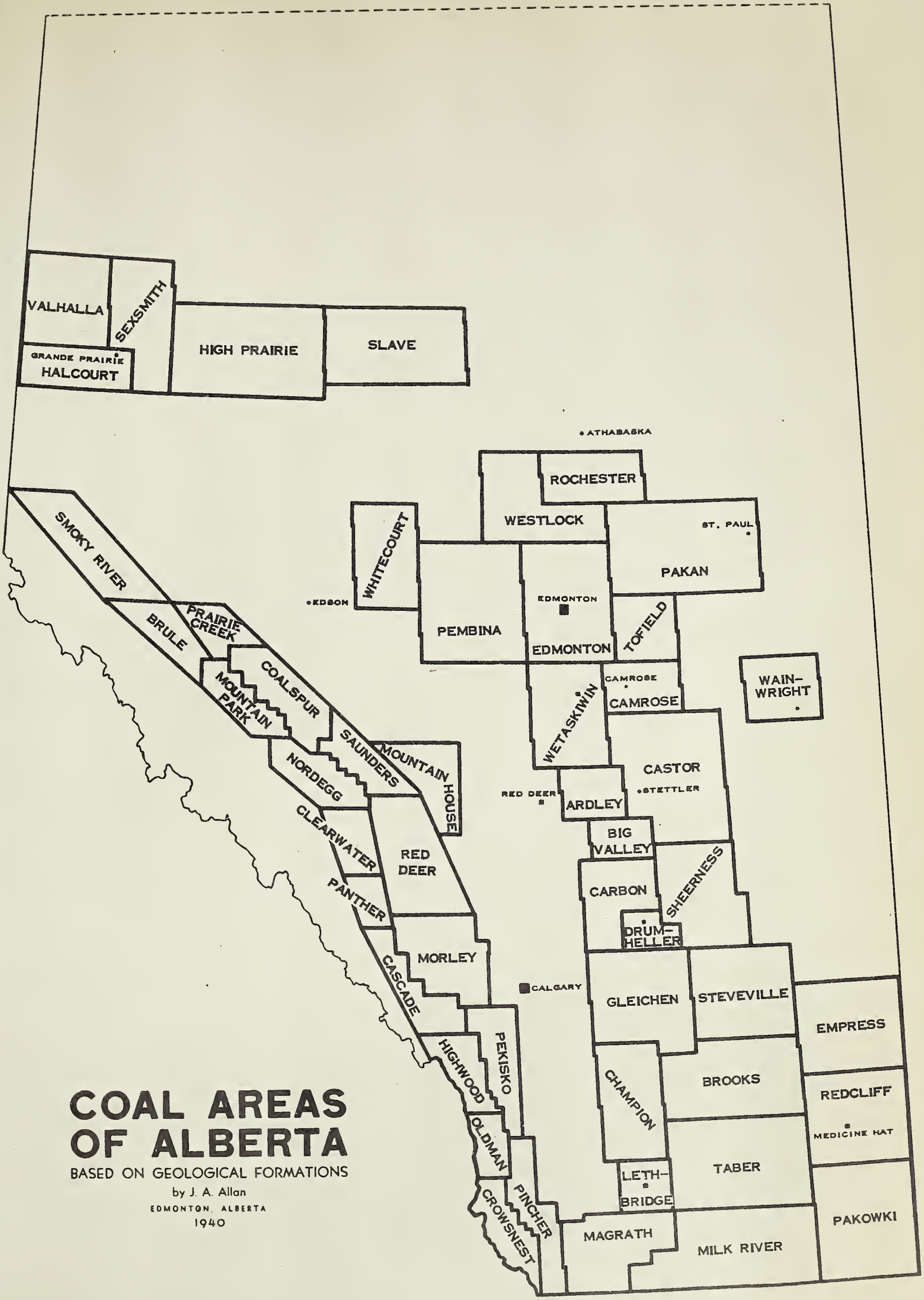
PEACE RIVER, ALBERTA COALS

Area	Thickness of seam (feet)	Depth of cover (feet)	Dip	Rank
Halcourt	1.5-2.3	0-150	---	high volatile C bituminous and sub-bituminous B
Sexsmith	3	30-40	---	sub-bituminous C
High Prairie	---	---	---	sub-bituminous C

The principal coal producing section of the Peace River district is the Halcourt coal area which occupies Townships 69-71, Ranges 5-13, west of the 5th meridian (Fig. 4, p. 57). Production from the rest of the Peace River district has been negligible up to the present.

Allan and Carr (1944, p. 40) reported the results of the survey in the Wapiti-Cutbank area as follows: ..... "it appears unlikely that thick coal seams will be discovered north of the Wapiti River". The known thin seams in this area have been mined with some success in the past (Allan and Carr, 1944, p. 26), but mining operations today are at their lowest ebb. Some occurrences on Pinto Creek and the lower part of the Cutbank River show some promise but there is no evidence to show that they would be economic deposits. The above evidence would indicate that deposits other than these would have to be discovered to provide adequate fuel supply for an iron industry.

Figure 4



COAL AREAS OF ALBERTA
BASED ON GEOLOGICAL FORMATIONS
by J. A. Allan
EDMONTON, ALBERTA
1940

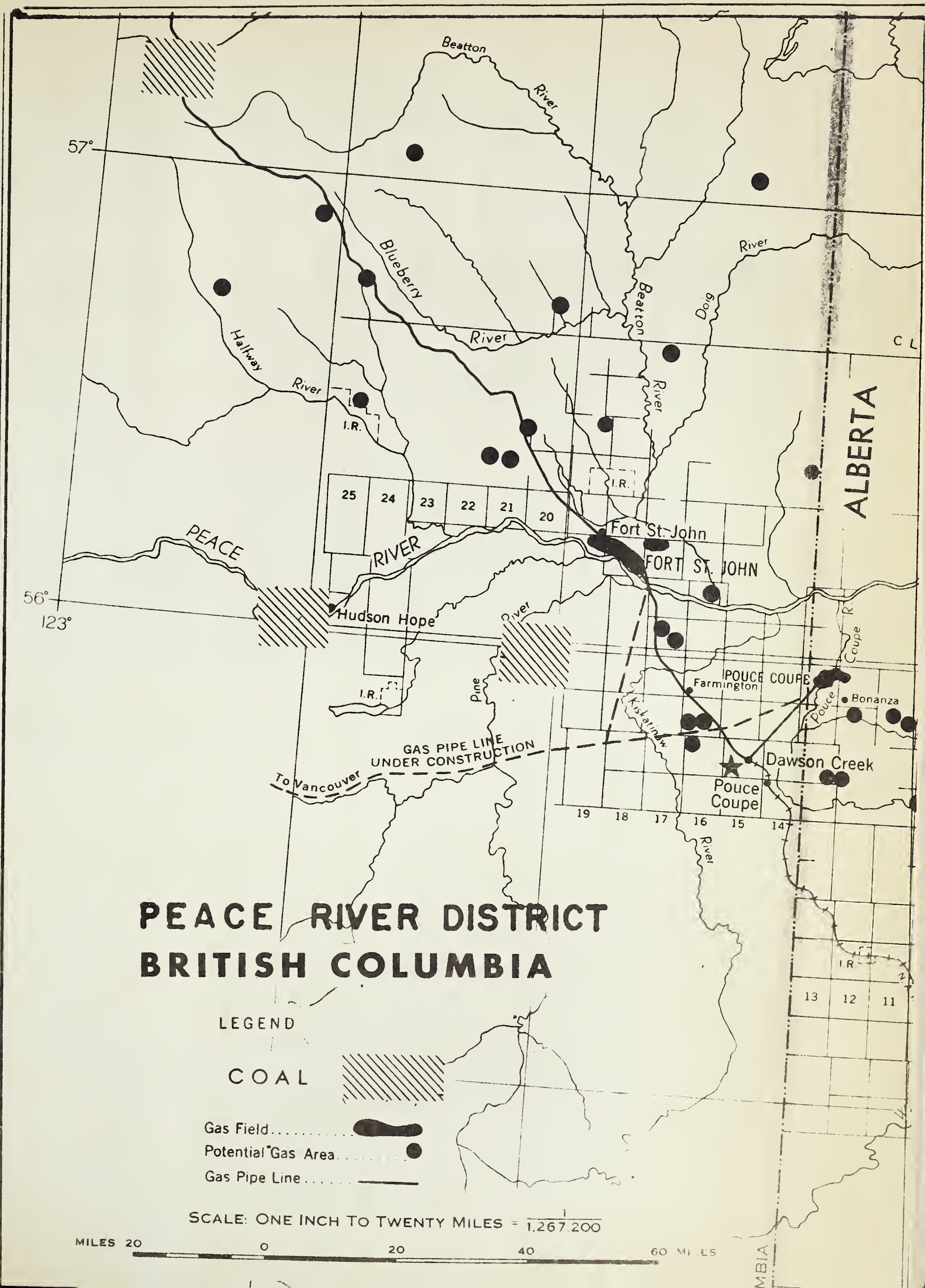
This assumption is based on the possibility that the initial concentration of iron would be carried out close to the source.

Peace River district, British Columbia: It has been known for some time that the Cretaceous rocks of this area had associated coal seams of fairly high rank and thickness (Dawson, 1879-80, p. 115B).

In the Peace River area coal deposits are found in the Gething formation of the Bullhead group, Lower Cretaceous in age. The Gething is correlated with the Luscar formation and the lower part of the Blairmore group on the basis of flora found in the following localities: (Fig. 5, p. 59) - Peace River Canyon coal area, Dunlevy Creek-Cust Creek-Butler Ridge area, Carbon Creek coal basin area, Fisher Creek-Pine River area, Hasler Creek coal area, and Halfway Sikanni Chief River area (McLearn and Kindle, 1950, p. 150). The Peace River canyon coal field is the best known of these; several small mines have operated from time to time during the past 25 years. The combined coal reserves of the six areas has been estimated by the Royal Commission on Coal (McKay, 1947) as 467,040,000 tons of probably mineable coal and with 573,440,000 tons of possible additional mineable coal.

The coals of the Peace River district, British Columbia, have low ash content and a high calorific value for a majority of the seams (Mathews, 1946, p. 20). According to the A.S.T.M. classification by rank, all of the coal seams in the Peace River foothills are either low volatile bituminous or medium volatile bituminous.

Figure 5


PEACE RIVER DISTRICT
BRITISH COLUMBIA
LEGEND
COAL ▨
Gas Field ....
Potential Gas Area .... ●
Gas Pipe Line ......
SCALE: ONE INCH TO TWENTY MILES = 1/1,267,200
MILES 20 0 20 40 60 MILES
57°
56°
123°
Beatton River
Blueberry River
Halfway River
Beatton River
Doig River
PEACE RIVER
Pine River
Kiskatinaw River
Pouce Coupe R.
I.R.
25
24
23
22
21
20
Fort St. John
FORT ST. JOHN
Hudson Hope
POUCE COUPE
Farmington
Bonanza
Dawson Creek
Pouce Coupe
GAS PIPE LINE UNDER CONSTRUCTION
To Vancouver
19
18
17
16
15
14
13
12
11
ALBERTA
CL
MBIA

The structure of this area varies, from the Plains areas flat structure through Foothills structures to the typical Cordilleran folded and faulted structural features. All coal seams are within economic depth and none exceed 1000 feet according to McLearn and Kindle (1930). The main factor in the lack of development of these coal areas is the absence of a large market in the area.

In the event that the Clear Hills iron is developed the logical source of coal is the Peace River Canyon and Pine Pass areas of British Columbia. It has already been shown that the coal areas of northwestern Alberta are inadequate.

Mileages on existing transportation routes (Northern Alberta Railways and Pacific Great Eastern Railroad) and also the direct lines distances from the railhead at Hines Creek to the coal areas of Alberta and British Columbia are as follows:

TABLE 7

MILEAGE TO COAL AREAS

Coal Areas	Distance from Hines Creek, Alberta	
	Line distance (miles)	Rail distance (miles - approx.)
Edmonton, Alberta	280	360
Grande Prairie, Alberta	75	225
Spirit River, Alberta	35	100
High Prairie, Alberta	100	130
Peace River, Alberta	50	60
Dawson Creek, British Columbia	75	300
Fort St. John, British Columbia	85	350
Hudson Hope area, British Columbia	130	400
Pine Pass area, British Columbia	175	400

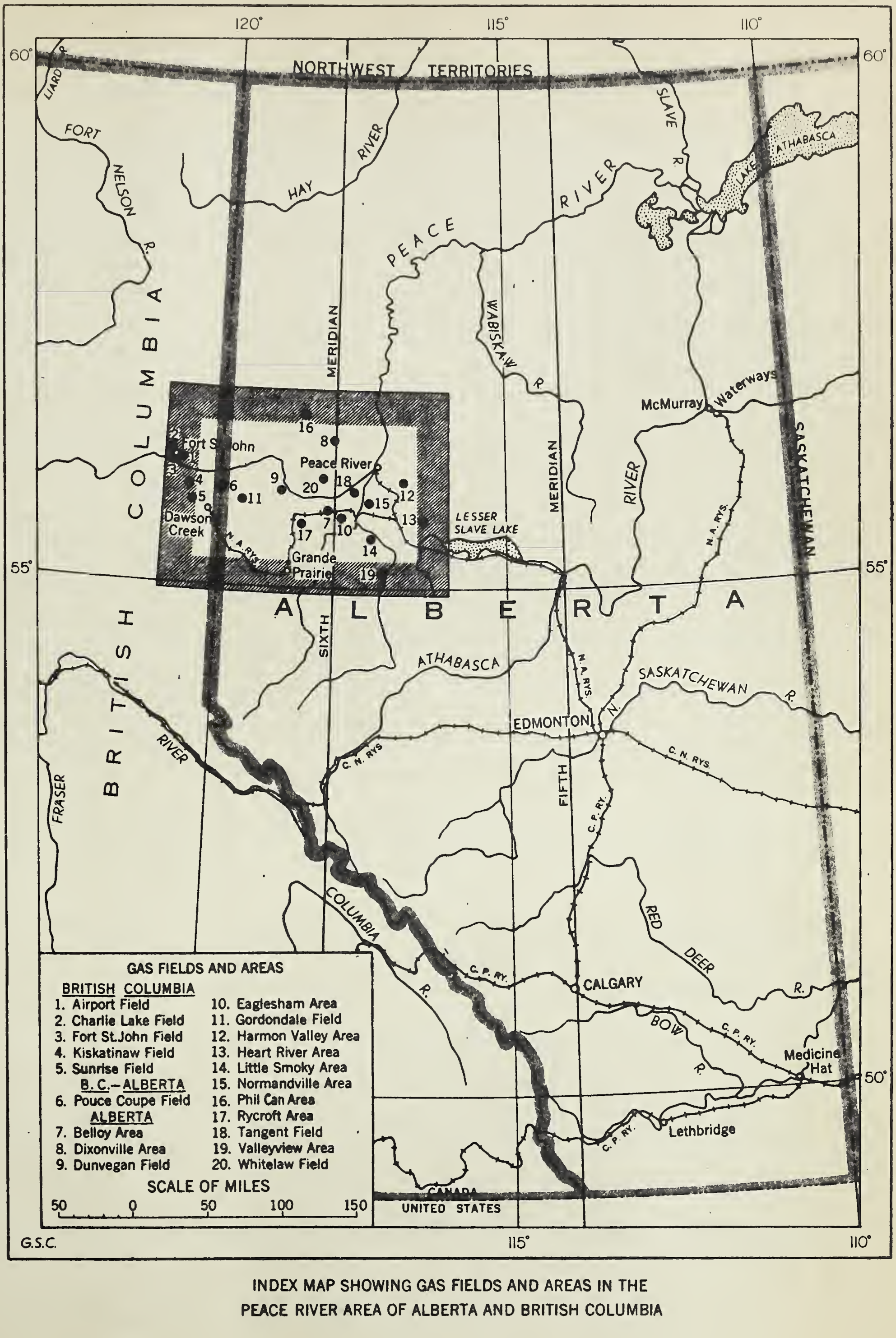
The table shows that the existing railroads, with their indirect routes, provide uneconomical haulage distances. The line distances to the British Columbia coal deposits are well within economic limits. If the iron or the coal is to be developed in this area it would be necessary to construct shorter, more direct railroads.

Limestone: The mountainous areas of the Peace River district of British Columbia afford an abundant supply of Triassic and Paleozoic limestones that might be suitable for use in a steel industry. Williams (1934) has pointed out that raw materials and fuel for the manufacture of Portland cement are available in close proximity in the Peace River district.

Limestone may be obtained 15 miles up Peace River above the mouth of the Nabesche. A plant site on the Pine River situated between the mouths of Le Moray and Mountain Creeks could obtain limestone within a radius of ten miles and coal on Pyramid Mountain within three miles.

Petroleum and Natural gas: The Peace River block and Hines Creek area in particular contains a large number of gas producing fields and wells (Fig. 6, p. 63). Natural gas and crude petroleum are produced or reserves are established throughout the area. Natural gas is by far the most abundant (Hume and Ignatieff, 1952). Here again is the possibility of a fuel source available on the site of the iron "ore" that could be used in the reduction and concentration of the iron, if additional gas reserves were made available for the

Figure 6



INDEX MAP SHOWING GAS FIELDS AND AREAS IN THE PEACE RIVER AREA OF ALBERTA AND BRITISH COLUMBIA

Peace River district. At the present time the reserves for this market are inadequate.

Iron: The preceding sections of this chapter have served as background information on the economic geology involved in the utilization of the low grade oolitic iron of the Clear Hills. This type iron deposit is not new to the steel industry of the world, especially in Europe. The North American steel industry, in the eastern portion of the continent, has been and still is fortunate in having extensive high grade deposits. The Clear Hills type of deposit presents many familiar problems in benefication and reduction and this has resulted in a general lack of interest by those capable of developing this low grade iron deposit in Alberta. The high silica content does not lend itself too well to the standard smelting procedures. Phosphorus content presents a problem though it might be eliminated or utilized. Sulphur does not appear to be present in all samples and may not be a problem. The silica could be eliminated by magnetic separation and flotation and is not present in more than the expected amounts for this type of "ore".

There are, however, many factors in favor of this deposit. A recent economic survey report by J.T. Donald & Co. (Economic Research Consultants), produced for Calgary Power Ltd., revealed a 123 million-dollar steel market in Alberta. At the present time 87 per cent of Alberta's steel is shipped into the province. It is mentioned in the survey that a steel industry using indigenous ores may be started in the province, opening the door for coke production from available coal resources on a large scale.

The Peace River area of northeastern British Columbia is served by the Pacific Great Eastern Railroad, which now extends from Vancouver to Taylor, British Columbia, half way between Fort St. John and Dawson Creek, British Columbia. It seems possible that this railway, which passes through the coal area of Peace River Canyon, could be extended into Alberta and the Clear Hills iron deposits by a more direct route than now exists.

Preliminary work by the McDougall-Segan Syndicate has proven a reserve of a billion tons. Their area of investigation was relatively small and it is felt that more extensive surveys will reveal billions of tons of low grade iron. Recent investigations by Premier Steel Co. Ltd. of Edmonton have disclosed a more accessible deposit near Worsley, 30 miles southwest of the original location, containing a favorable calcium carbonate content.

Fuel should be no problem because of large coal reserves less than 150 miles from the deposit. Natural gas on the location could possibly be used in the pelletizing process but the present reserves of natural gas are insufficient for the present Peace River market. This might be alleviated by further discoveries but the possibilities remain in doubt. Hydro power sites are available in British Columbia's Peace River Canyon, where 400,000 horsepower could be developed to provide the power required (Camsell, 1947, p. 77). The recently completed Royal Commission Report on Canada's Economic Prospects (November, 1957) gives hydro power remaining to be developed on the Peace River in northeastern British Columbia as 3 million

kilowatts (Gordon, 1957, p. 141).

A recent news release (June 17, 1958, Edmonton) reported that the British firm of Thomson-Houston is investigating five possible hydro-power sites in the Peace River Canyon of northeastern British Columbia.

Mining of the material would not present any difficulty. In most locations the overburden is light and the "ore" itself could be removed by standard open pit methods.

The Clear Hills is not a "Mesabi" or a "Labrador" but does compare favorably with the Minette ore of France of the Salzgitter of Germany in character and composition, and, with the sizable existing steel market and the possibility of over 2 million people in Alberta by 1975, this deposit may be competitive with steel from eastern sources.

CHAPTER VI

CONCLUSIONS

The oolitic iron of the Clear Hills in its present location appears to be a reworked sedimentary iron deposit. The oolitic iron was initially laid down as a primary material in a brackish marine lagoon in an environment which was favorable to the deposition of iron carried in solution by rivers from the source areas. As the deposition progressed, changes in pH, the abundance or lack of oxygen, variable amounts of organic debris, allowed the precipitation of the limonite-goethite to alternate with the Fe carbonate facies. This could take place as indicated above or it could be a simple replacement of primary siderite.

It is believed that the "ore" is of marine or marginal marine to brackish-water origin. The oolitic structure is characteristic of marine environment and the presence of chamosite, considered to be exclusively a marine environment mineral, substantiates this theory. The oolites were probably formed by colloidal processes and if not, as siderite directly. The oxides were reduced on the bottom or slightly beneath the surface of deposition. Variations in composition of the deposit suggest a gradual change to conditions more favorable to the oxide facies. Probable deepening of the water by influx of the sea resulted in turbulent flow aerating the waters and produced normal oxygen content. The presence of fragmentary ooliths, chert fragments, secondary calcite and rock fragments containing ooliths

gives the deposit all the appearance of a primary deposit eroded and redeposited mechanically. The source of the original primary iron is believed to be to the west. The mineralogy indicates an igneous source, possibly the Topley batholith undergoing deep tropical erosion. Iron was probably carried as a colloid by large sluggish streams incapable of carrying large suspended loads.

Any clastic material would probably be dropped before the zone of iron deposition was reached. The microscopic appearance of the oolith shells suggests colloidal conditions and this would mean that iron (colloids) in solution would have to come in contact with the saline sea waters to be precipitated. This would carry the iron beyond the clastic trap basin. The general scarcity of clastic material in the deposit suggests that it has not been transported very far from the original bed of deposition. Quite probably the deposit was merely ripped to pieces by wave action as the sea level rose.

The Clear Hills oolitic iron "ore" compares favorably with most of the known oolitic iron ore deposits of the world. Considering the well known deposits of this type it appears that the Cleveland Hill deposits of England present the most interesting comparison. The histories of deposition of both the Clear Hills and the Cleveland Hill deposits from the evidence at hand have much in common.

There is a substantial market for steel in Western Canada. The possibilities of this market expanding are very good. There are large tonnages of low grade iron in the Clear Hills deposit.

A minimum estimate is approximately one billion tons (McDougall, 1954). Fuel in the form of coal, and hydro-electric power resources are available for development in the Peace River Canyon area of British Columbia within economic line distance of the iron deposit.

APPENDIX

Color Photography

Color photographs of the outcrop and the area and color photomicrographs of thin sections contribute much to the description of this iron "ore". It can be readily seen that color was practically essential in the descriptions and black-and-white photographs would be of little value except in visualizing texture and structure of the material. The thickness of the oolitic thin sections prohibited the use of the Nicol prism in most cases.

Considerable time and money were expended in preparation of the color plates but it is felt that the expenditure was necessary and rewarding. The following information is given as an aid to anyone doing this type of work in the future.

Field photography: This particular aspect is the simplest of the two projects and the essentials are a good camera and daylight film (color) to suit the individual's purpose. The field color plates in this thesis were procured using a Zeiss Contaflex "C" 35 mm. camera, with a built-in exposure meter. The film used was Kodak Ectochrome daylight - A.S.A. No. 32. This film was used mainly because of past success, economy, and the fact that it can be developed locally. The exposures used were governed by the light meter readings. The results are almost always good. All hand specimen photographs were taken using the above equipment and available light.

Color photomicrographs: This work was carried out using the Geology Department's equipment, which is described below.

Microscope - Leitz polarizing, Model KM-L, No. 502442

Eyepiece lens - 8 magnifications

Objective lens - low power 3.2 - 10 diameter
medium power 10.1 - 30 diameter

Attachments - Leitz photomicrograph apparatus with bellows extension (40 cm.)

Camera - Leitz Leica 1 f., 35 mm., No. 682345

Filter - White or light blue in light source attachment on microscope

Light - Full scale light - pin point at light source in combination with convergent lens

Film - Ansco - Super Anscochrome
Tungsten 35 mm., A.S.A. No. 100 - 20 exposures

Exposure time - Several test runs were made on time exposure and the best exposure times using the magnification and light conditions described are as follows:

for low power 10 diameter 1 sec.
for medium power 30 diameter 1/2 sec.

Prints - All photographs were developed as transparencies and the better ones selected for printing. These were printed and enlarged (6 diameters) by Pix-a-Color Ltd. of Edmonton. The results were good. Even though it is still impossible to get exact color duplication the resulting colors were very close to the originals, considering that this was a first attempt with this very fast film.

LIST OF THIN SECTIONS - CLEAR HILLS

Field Number	Thin Section Number	Location	* Interval (feet)
CH-1	3076	Swift Creek - A	26'-28'
CH-2	3077	" " - A	24'-26'
CH-3	3078	" " - A	22'-24'
CH-4	3079	" " - A	20'-22'
CH-5	3080	" " - A	18'-20'
CH-6	3081	" " - A	16'-18'
CH-7	3082	" " - A	14'-16'
CH-9	3083	" " - A	10'-12'
CH-11	3084	" " - A	6'-8'
CH-16	3085	" " - A Nodule	14'-16'
CH-15	3086	" " - B	6'-8'
CH-17	3087	" " - A Nodule	16'-18'
CH-21	3088	" " - A	10'-12'
CH-20	3089	" " - A Fossil wood	14'-16'
CH-22	3090	" " - A	-17'-
CH-23	3091	" " - B	-16'-

* All depths from surface (Till 4 feet).

CHEMICAL ANALYSES OF OOLITIC IRON
(SWIFT CREEK, CLEAR HILLS)

Sample No.	Thin Section No.	Footage (from surface)	Oxide Percent by weight		
			Fe^{++}	Fe^{+++}	Total Iron
TILL		0'-4'			
CH-12	* No thin section	4'-6'	0.27	33.19	33.46
CH-11	3084	6'-8'	1.52	30.56	32.08
CH-10	* No thin section	8'-10'	0.50	31.93	32.08
CH-9	3083	10'-12'	1.53	30.12	31.65
CH-8	* No thin section	12'-14'	2.12	34.03	36.15
CH-7	3082	14'-16'	10.58	16.58	27.20
CH-6	3081	16'-18'	6.12	21.12	27.24
CH-5	3080	18'-20'	10.54	13.11	23.65
CH-4	3079	20'-22'	10.35	13.46	23.81
CH-3	3078	22'-24'	7.92	13.88	21.80
CH-2	3077	24'-26'	21.92	3.18	25.10
CH-1	3076	26'-28'	19.00	0.14	19.14

* Material too soft and friable for thin section

(Chemical analyses done by G.M. Hughes and G.L. Colborne)

ANALYSES OF SWIFT CREEK OOLITIC IRON SAMPLES FOR CLIFFS OF CANADA*

Lab. No.	Sample No.	Total Iron	Loss on Ignition	Interval (in feet)
30-716	CH-1	27.26	17.35	0-2 Location A
717	CH-2	26.94	22.31	2-4 " "
718	CH-3	28.94	18.92	4-6 " "
719	CH-4	27.98	13.67	6-8 " "
720	CH-5	27.90	13.36	8-10 " "
721	CH-6	27.42	13.49	10-12 " "
722	CH-7	30.05	13.47	12-14 " "
723	CH-8	30.77	12.57	14-16 " "
724	CH-9	34.77	11.73	16-18 " "
725	CH-10	33.97	12.91	18-20 " "
726	CH-11	33.73	11.74	20-22 " "
727	CH-12	35.73	12.74	22-24 " "
728	CH-13	27.26	13.81	0-12 Comp.
729	CH-14	33.65	12.05	12-24 Comp.
730	CH-15	31.49	13.69	Location B Type sample
731	CH-16	30.37	20.94	Location A
732	CH-17	35.41	22.65	Nodule at A
733	CH-18	11.91	14.27	Band in till

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* Analyses carried out by Steep Rock Iron Mines Ltd., Steep Rock, Ontario, (1957).

ANALYSES OF CORE HOLE SAMPLES
(McDougall, 1954, p. 10)

- 5 foot intervals -

Sample No.	E-1A+	E-3B	E-3C	E-4C	E-4D
L.O.I.	13.64	12.57	12.52	12.98	12.63
SiO_2	27.49	27.34	48.46	34.05	37.89
Fe_2O_3	50.10	50.58	28.02	41.55	35.47
Al_2O_3	6.11	5.95	6.00	6.55	7.70
MgO	2.62	2.34	2.68	2.63	3.30
CaO	0.00	0.19	0.00	0.00	0.00

Sample No.	E-1B	E-2A	E-2B	E-3A	E-4A
L.O.I.	16.32	12.80	16.37	15.35	14.56
SiO_2	23.18	31.68	19.93	21.52	23.80
Fe_2O_3	46.40	43.84	52.94	51.98	52.46
Al_2O_3	7.25	7.40	6.55	6.30	5.80
* MgO + CaO	4.68	2.53	2.87	1.31	1.60

Sample No.	E-4B	E-5A	E-5B	E-5C	E-5D
L.O.I.	13.75	12.93	16.37	15.24	13.76
SiO_2	27.34	26.14	25.57	24.70	27.36
Fe_2O_3	49.47	48.88	48.88	46.67	45.98
Al_2O_3	6.50	7.40	6.50	8.05	7.45
* MgO + CaO	2.60	2.64	1.66	3.32	2.95

* Calculated as MgO

+ E-1A - E = Eureka - 1 = hole number - A = interval

POSSIBLE TOTAL IRON FROM MCDOUGALL ANALYSES (McDougall, 1954, p. 11)

Sample No.	Percent Iron
E-1A	40.5
E-1B	38.8
E-2A	35.1
E-2B	44.3
E-3A	42.9
E-3B	40.4
E-3C	22.4
E-4A	42.9
E-4B	40.1
E-4C	33.4
E-4D	28.4
E-5A	39.2
E-5B	40.8
E-5C	38.4
E-5D	37.3

Spectrographic Analyses of McDougall Samples by K.B. Newbound, Physics Department, University of Alberta. (McDougall, 1954, p. 12).

Iron - major constituent
Magnesium - less than 10 percent
Silicon - lines weak, element difficult to excite
Sodium - less than 1 percent
Calcium - less than 1 percent
Chromium - presence not definitely established but possible
Sample 5D - contained some tin.

LIST OF THIN SECTIONS - HIGHWOOD RIVER AREA

Field Number	Thin Section Number	Location	* Interval (feet)
HW-1	3092	Contact Creek Pit-1	Blackstone-Cardium contact
HW-2	3093	" " " "	0'-1'
HW-3	3094	" " " "	1'-3'
HW-5	3095	" " " "	3'-5'
HW-6	3096	" " " "	5'-7'
HW-7	3097	" " " "	7'
HW-9	3098	" " " "	7'-10'
HW-10	3099	" " " "	10'-12'
HW-11	3100	" " " "	12'-15'
HW-12	3101	" " " "	15'-20'
HW-13	3102	" " " "	20'-25'
HW-14	3103	" " " "	Nodules 15'-25'
HW-15	3104	" " Pit-2	Basal bed
HW-16	3105	" " " "	Middle bed
HW-17	3106	" " " "	Top beds

* Footage reads from Blackstone-Cardium contact upwards.

* ANALYSES OF FERRUGINOUS SANDY SHALE - BLACKSTONE-CARDIUM CONTACT, CONTACT CREEK-HIGHWOOD RIVER AREA FOR CLIFFS OF CANADA

Lab No.	Sample No.	Total Iron	Silica	Loss on Ignition	Interval
28-889	HW-1	23.15	25.39	19.62	Blackstone-Cardium contact
890	2	23.47	28.32	10.95	Pit-1 0'-1'
891	3	26.60	16.17	21.18	1'-3'
892	4	28.29	21.45	14.39	Oxidized at 3'
893	5	31.51	16.45	17.59	3'-5'
894	6	27.65	15.34	20.77	5'-7'
895	7	34.40	11.22	20.07	Base oxidized zone at 7'
896	8	42.68	11.23	19.86	Oxidized zone 7'
897	9	23.71	16.37	24.48	7'-10'
898	10	15.75	19.50	22.50	10'-12'
899	11	11.73	30.07	17.77	12'-15'
900	12	2.57	33.78	20.00	15'-20'
901	13	1.93	57.18	15.73	20'-25'
902	14	6.27	80.20	4.90	Nodules 15'-25'
903	15	39.06	12.27	18.00	Pit-2 Basal bed
904	16	35.28	13.28	16.99	Middle bed
905	17	31.10	12.72	17.78	Top beds
906	18	1.61	93.40	1.98	Overlying sandstone

* Analyses carried out by Steep Rock Iron Mines, Ltd., Steep Rock, Ontario (1957).

A COMPARISON BETWEEN OOLITIC ORE DEPOSITS

Geographic location		Clinton hard ore, U.S.A.	Lorraine Minette ore, France	Cleveland-Hill ore, England	Wabana ore, Newfoundland	Salzgitter ore, Germany		Clear Hills ore, Alberta, Canada
						High grade	Low grade	
Mineralogical composition		Hematite	Limonite Siderite Hematite	Chamosite Siderite	Hematite Chamosite Siderite	Siderite	Siderite	Limonite-goethite Siderite-chamosite?
Geological age		Silurian	Jurassic	Jurassic	Ordovician	Cretaceous	Cretaceous	Cretaceous
Associated rocks		Limestone Shale	Shales, sandstone, marl	Shale	Sandstone Shale	Sandstone Shale	Sandstone Shale	Sandstone Shale
Chemical composition	Fe	37.0	30.0	36.0	20-57	32.60	29.70	30.15
	Mn	0.23	----	----	----	0.22	0.12	0.15
	P	0.30	0.5-1.8	0.55	0.7-2.0	0.37	0.48	0.58
	SiO_2	7.14	7.2	8.51	6.50	27.00	27.80	25.36
	Al_2O_3	3.81	----	6.12	3-6	10.17	5.60	6.24
	CaO	19.20	12.0	5.74	1.30	0.16	3.95	* ----
	H_2O	----	----	3.75	----	1.65	1.48	----
	S	0.08	----	0.05	----	0.16	0.05	+ 0.701

* Sometimes present

+ Not always present

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Plate I

A. - View looking southwest from Notikewin forestry tower, Clear Hills, Alberta

B. - Emergency landing strip one mile south of Notikewin forestry tower, built on glaciolacustrine silt

Plate II

A. - Seismic winter road to Swift Creek
from forestry road

B. - 25-foot exposure of oolitic iron
on Swift Creek

Plate III

A. - Well weathered outcrop - good example of "earthy" appearance

B. - Fresh exposure of oolitic iron showing nodular texture and fracture pattern

Plate IV

A. - Basal bed of exposure on Swift Creek - note grey-green color and nodular texture

B. - Upper beds in relatively fresh exposure - note rich red-brown color

Plate V

A. - Upper beds, location "B" on Swift Creek. Fractures due to frost action

B. - Fresh surface exposed after wedge shown in A. was removed.

Plate VI

A. - Hand specimen CH-9, upper beds, oolitic iron, Swift Creek

B. - Disaggregated iron "ore", upper beds, sample CH-10

1
2
3
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2
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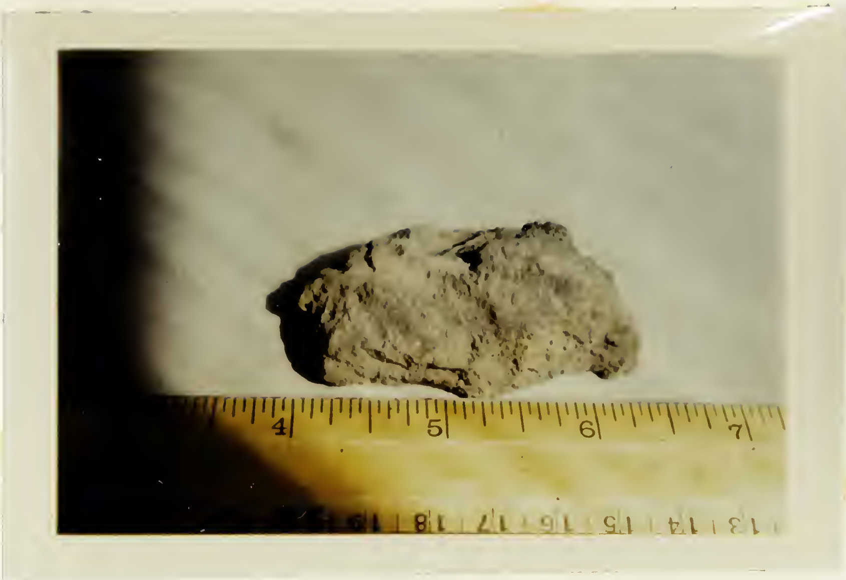
Plate VII

A. - Hand specimen CH-1, basal beds, Swift Creek

B. - Hand specimen, section of fossil wood fragment, sample CH-20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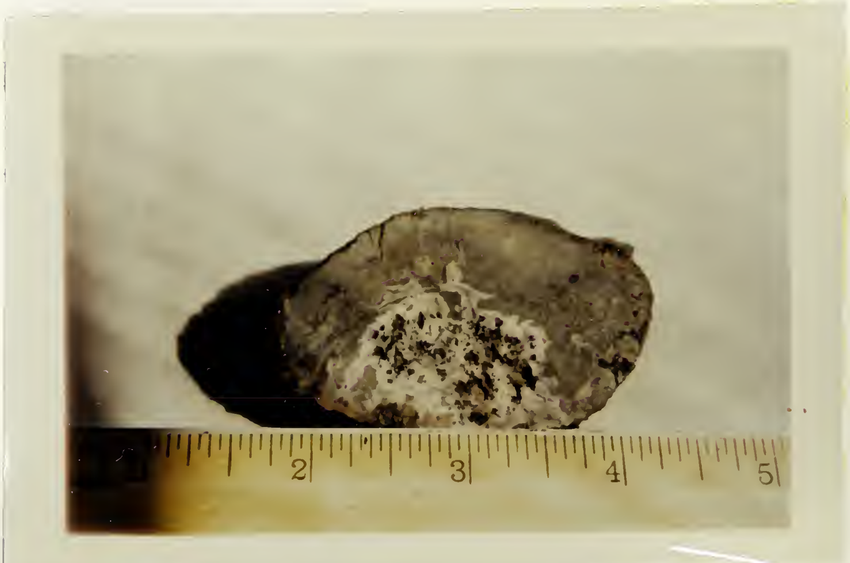
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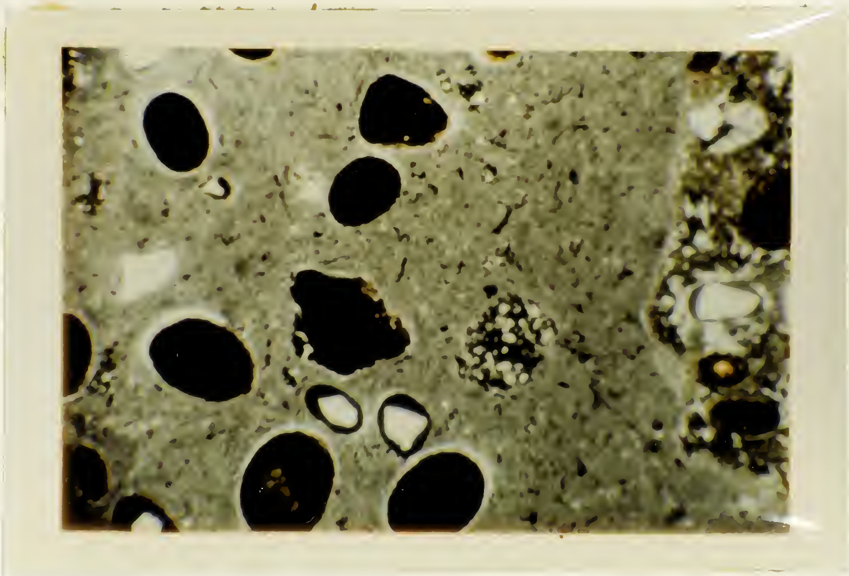
Plate VIII

A. - Sample CH-17 - nodule from middle beds, location "A" made up of sideritic-chamositic mudstone, ooliths. Quartz and ooliths included in rock fragments. Thin section 3087, 60 diameters

B. - Same as A., showing more of rock fragment. Thin section 3087 - 60 diameters



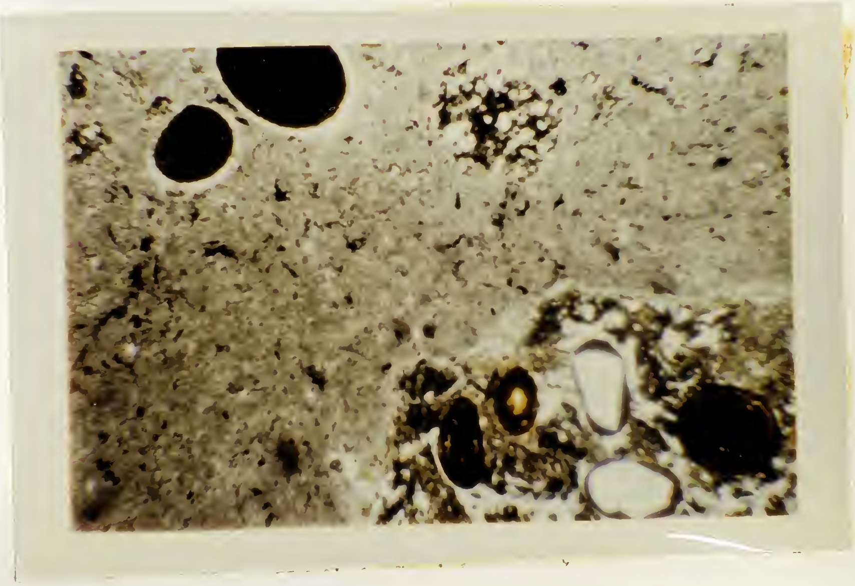
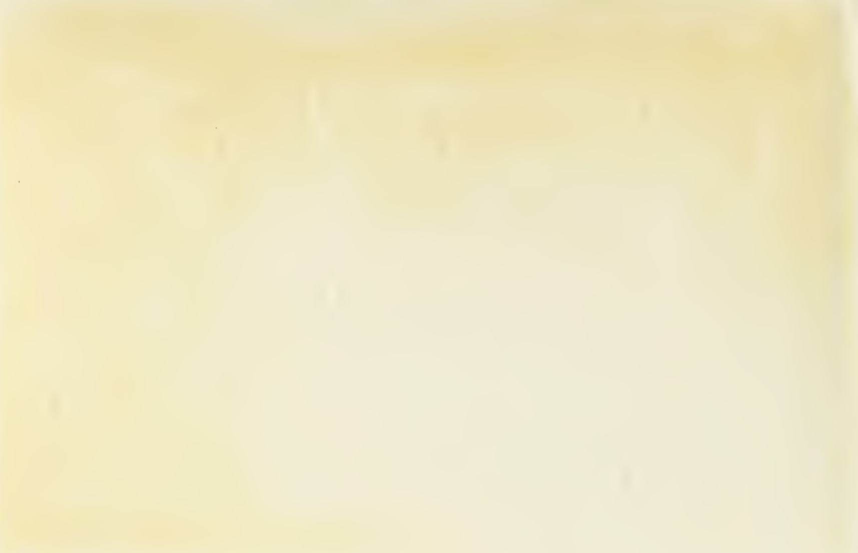
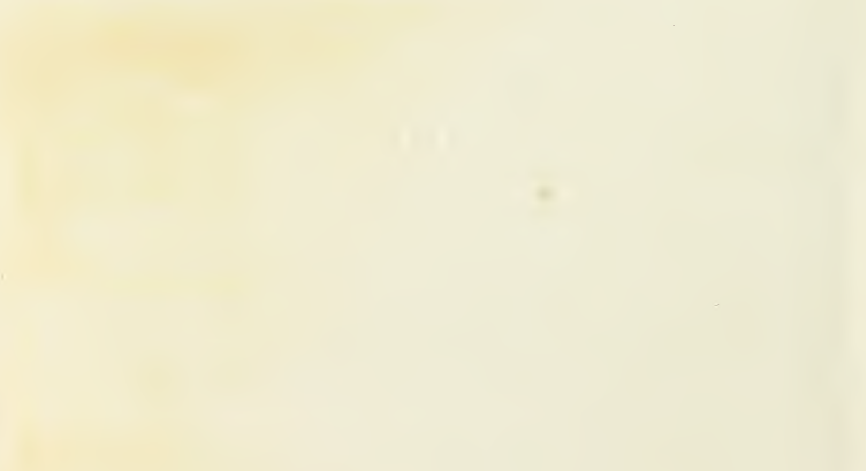


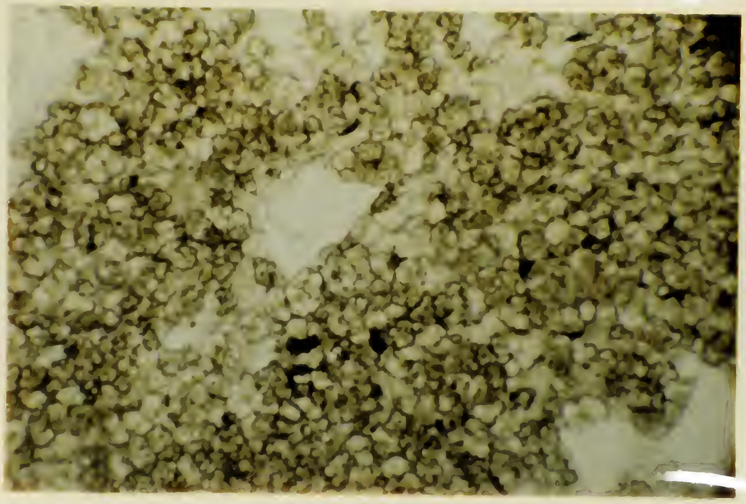
Plate IX



A. - CH-1, basal beds, location "A", Swift Creek.
Spherulitic siderite, quartz fragments and carbonaceous matter.
Thin section 3076 - 180 diameters



B. - Examples of the various sizes, shapes and material making up nuclei plus rock fragments with feldspar inclusions.
Thin section 3079 - 60 diameters



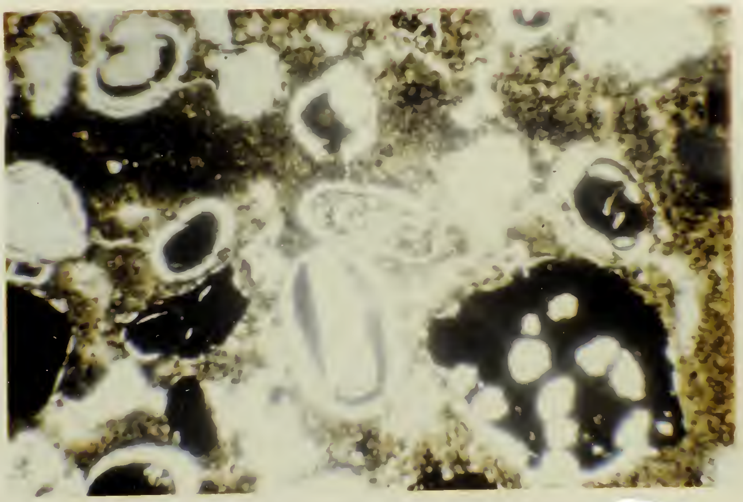
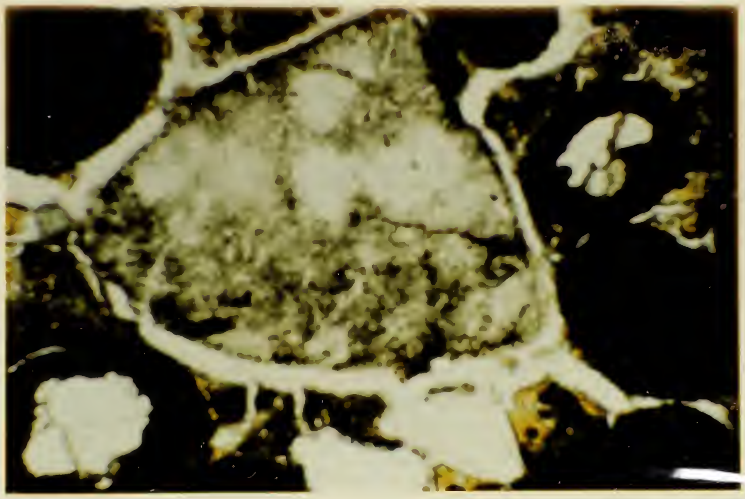


Plate X

A. - Chamosite fragment (x - nicol prism) - note replacement of quartz nucleus in oolith top right corner.
Thin section 3091 - 180 diameters

B. - Siderite oolith, almost complete replacement of quartz nucleus, matrix spherulitic siderite.
Thin section 3080 - 180 diameters



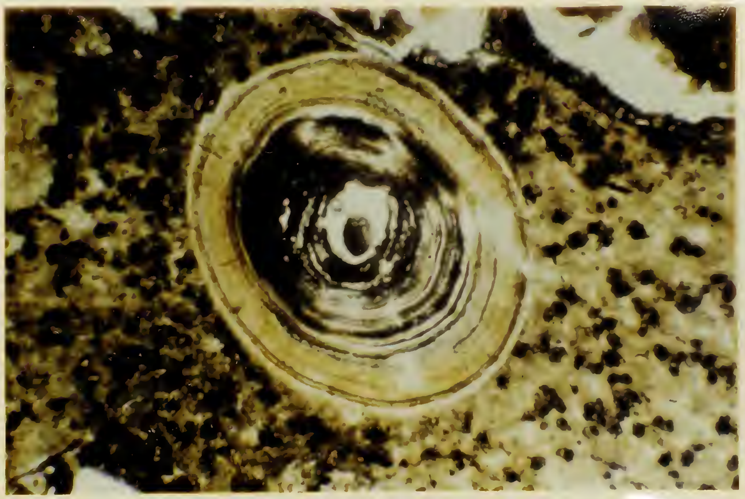
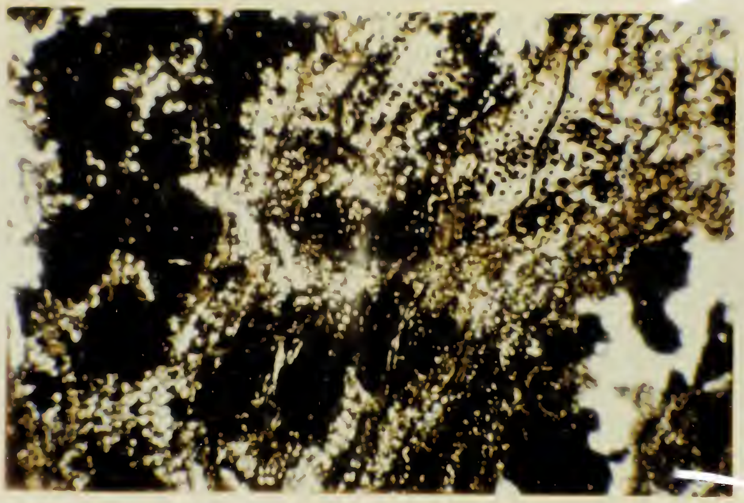


Plate XI

A. - Fossil wood from location "A", Swift Creek - note excellent definition of cellular structure. Thin section 3089 - 60 diameters

B. - Same as A.
Thin section 3089 - 180 diameters



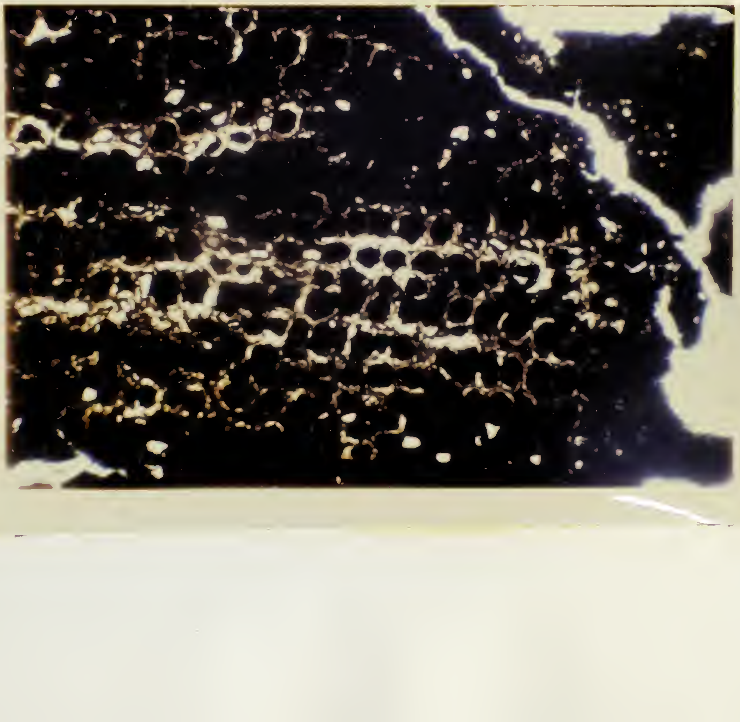
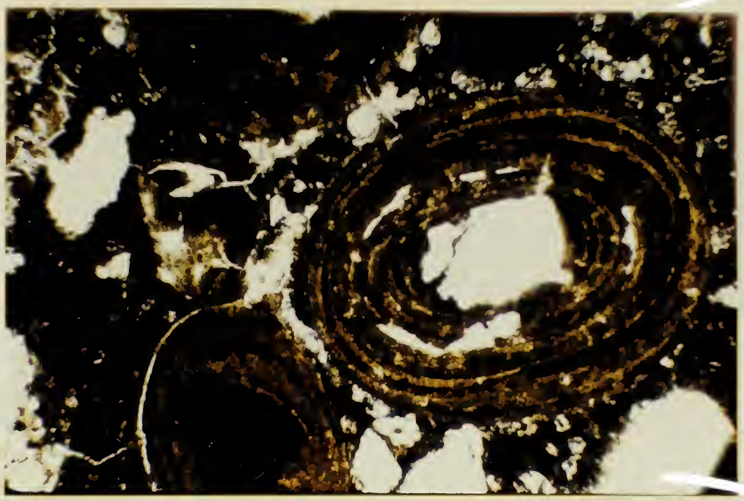


Plate XII

A. - Perfect example of alternating concentric shells of siderite (yellow) and limonite-goethite (brown-black) and definite replacement of quartz nuclei.
Thin section 3080 - 180 diameters

B. - Note close packing of ooliths typical of upper beds - siderite makes up substantial percentage of ooliths. Thin section 3091 - 60 diameters



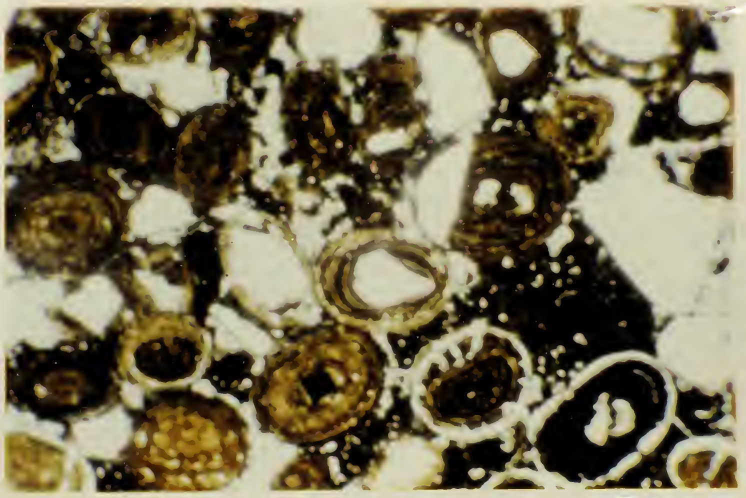
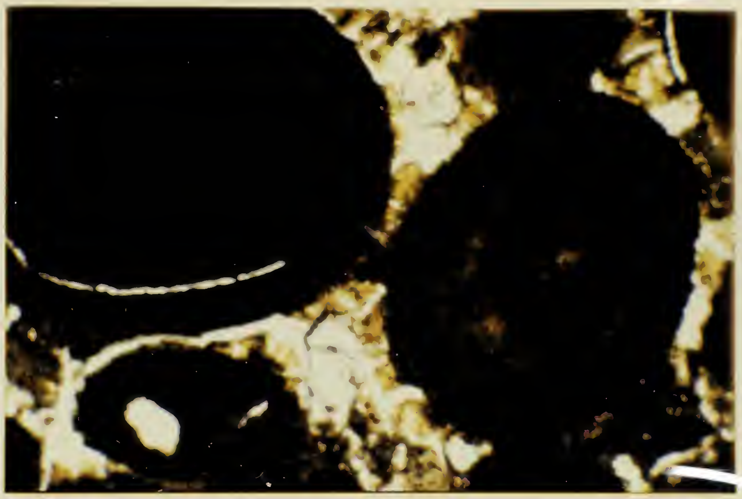


Plate XIII

A. - Crossed nicols prism, limonite-goethite, opaque, siderite yellow, quartz white, some nuclei limonite-goethite.
Thin section 3080 - 180 diameters

B. - Examples of distorted ooliths and oolith fragments and many quartz nuclei almost entirely replaced.
Thin section 3079 - 60 diameters



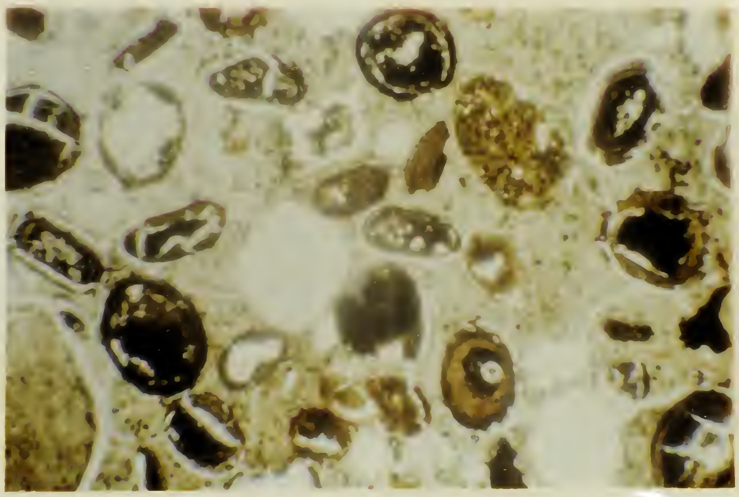
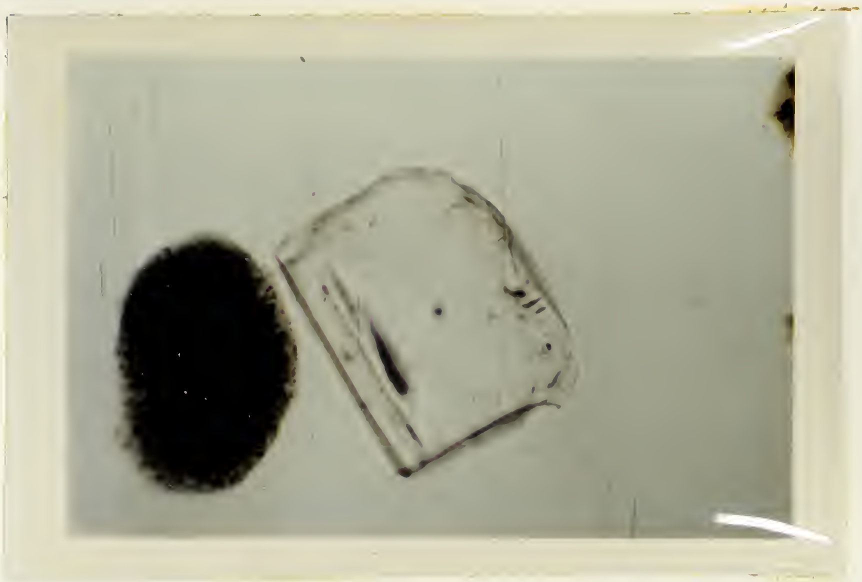


Plate XIV

A. - Sanidine (?) feldspar crystal - Canada Balsam mount 3224 (A^{40}/K^{40}) - 180 diameters

B. - Quartz separated from "ore", Canada Balsam mount 3224 (A^{40}/K^{40}). Partial replacement of quartz by iron oxide. 180 diameters



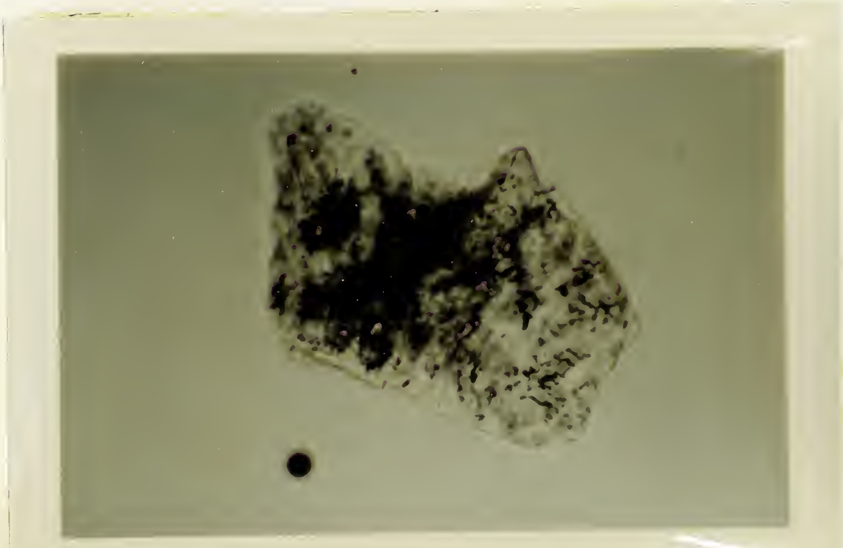
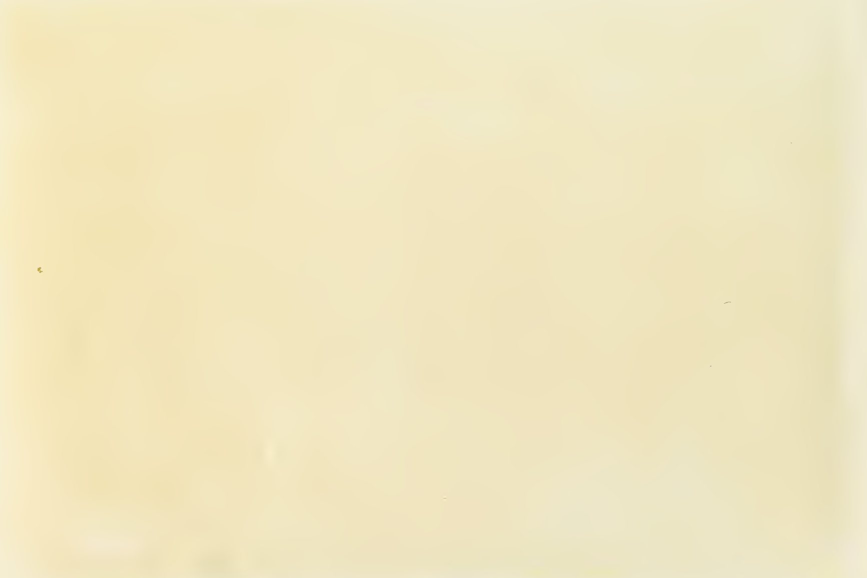


Plate XV

A. - Highwood River area, Contact Creek valley, Pit No. 1 on west side of valley - "King Bearpaw claim".

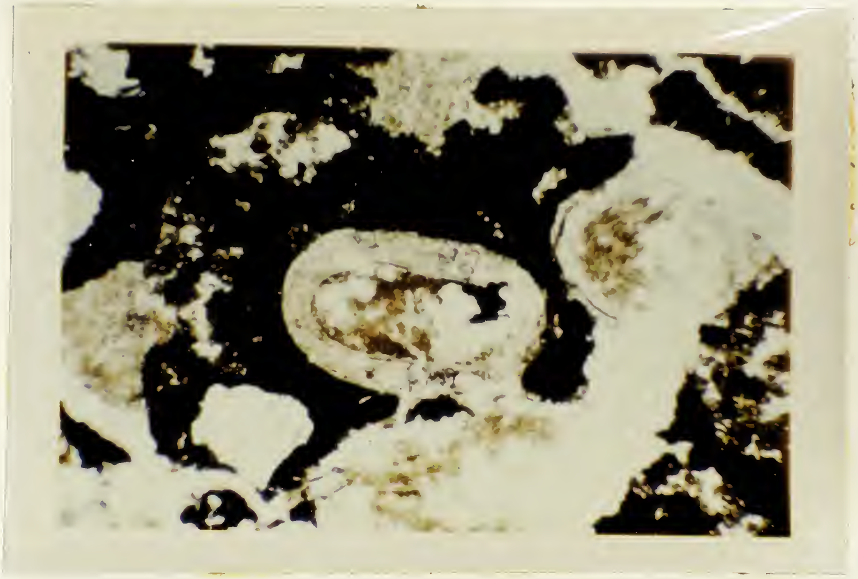


B. - Pit No. 1 - Contact Creek. Heavily oxidized replacement zone above Blackstone-Cardium contact

Plate XVI

A. - Calcite ooliths, quartz nucleus, in hematitic sandstone (Highwood).
Thin section 3095 - 180 diameters

B. - Hematite replacement in sandstone (Highwood).
Thin section 3104 - 180 diameters



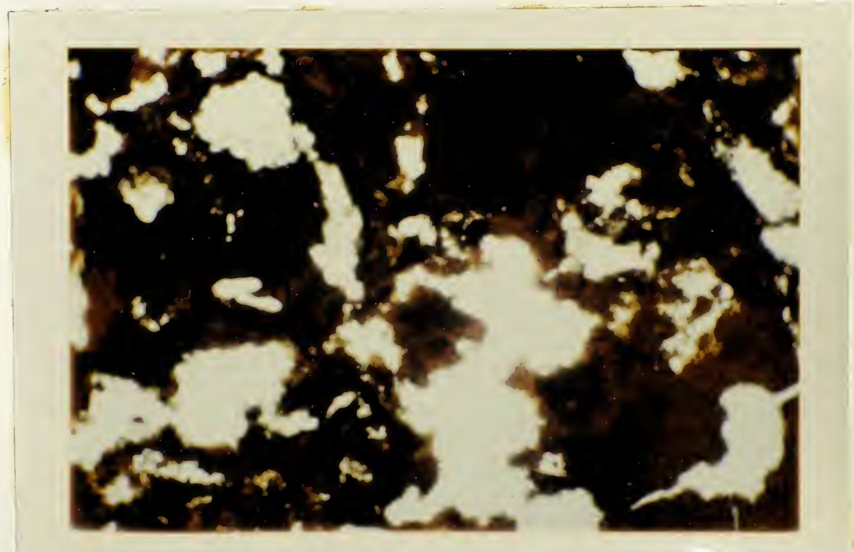
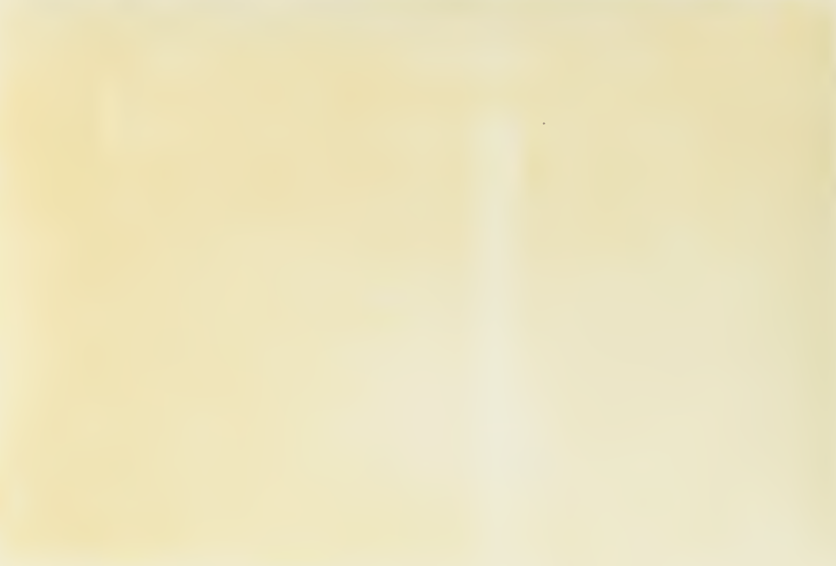
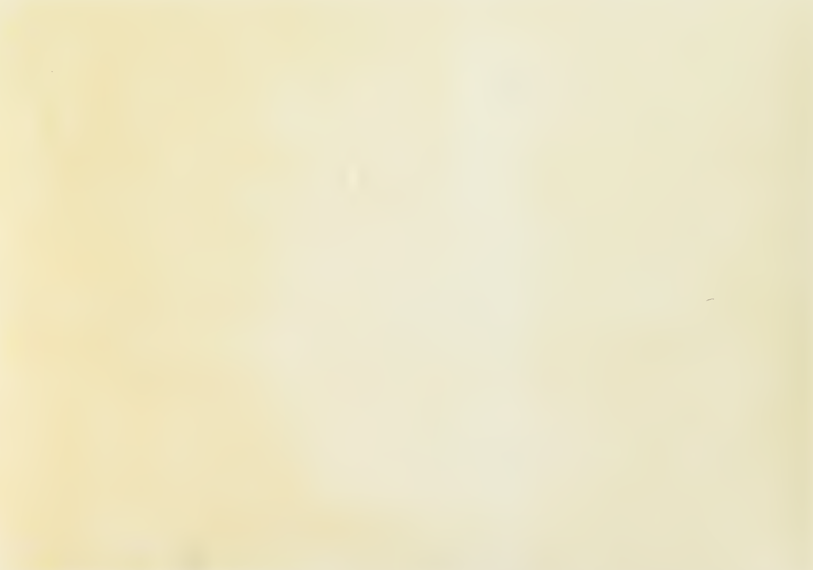


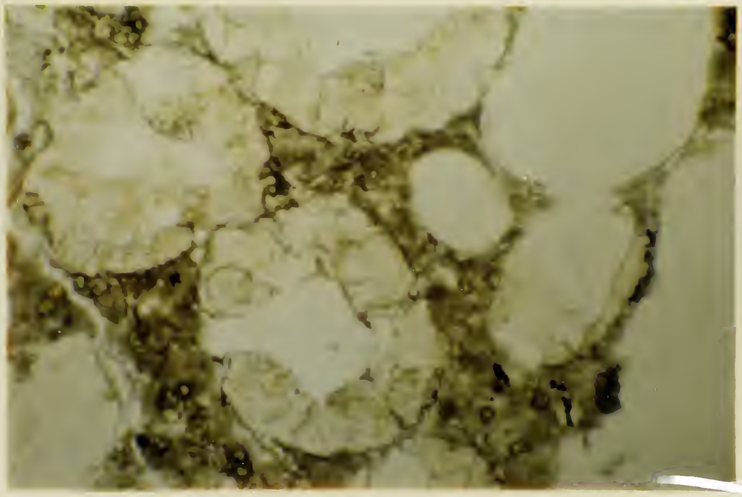
Plate XVII

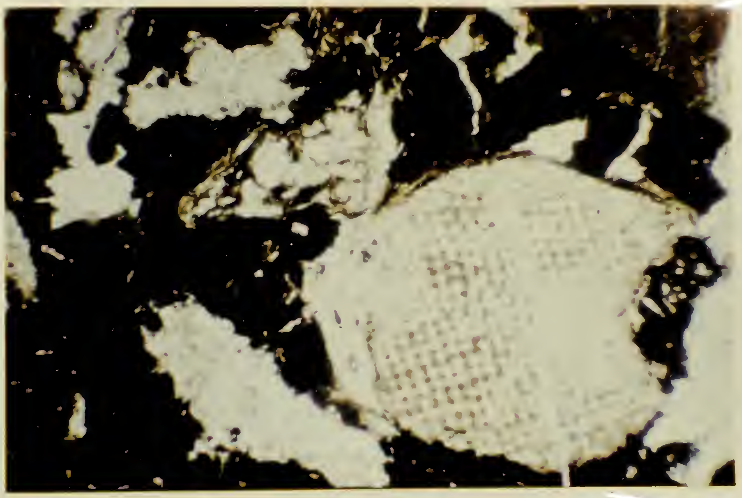


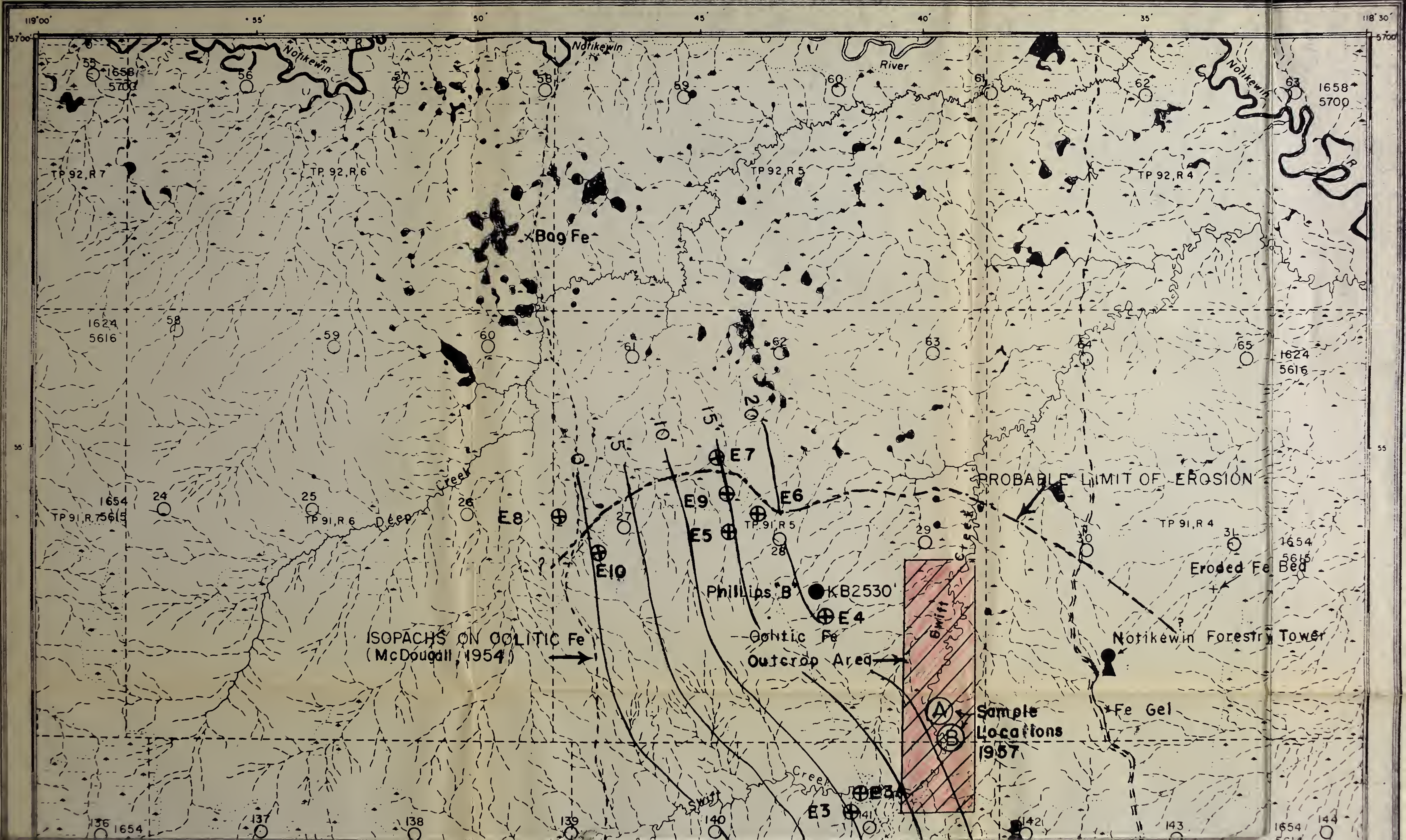
A. - CH-22, 16 feet from top of exposure, location "A", Swift Creek - calcite spherulites in sideritic-chamositic matrix - secondary calcite replacement of siderite. Thin section 3090 - 180 diameters

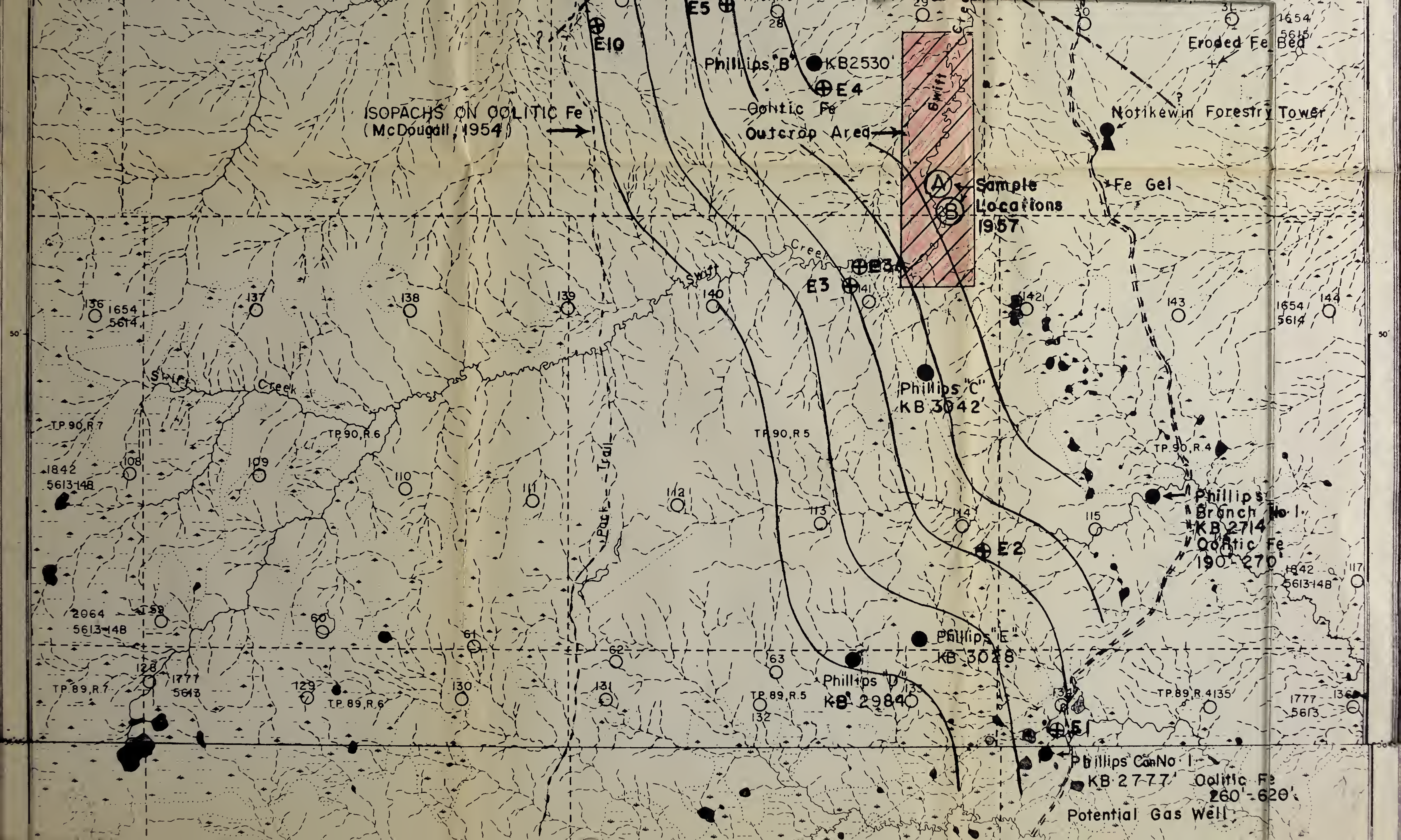


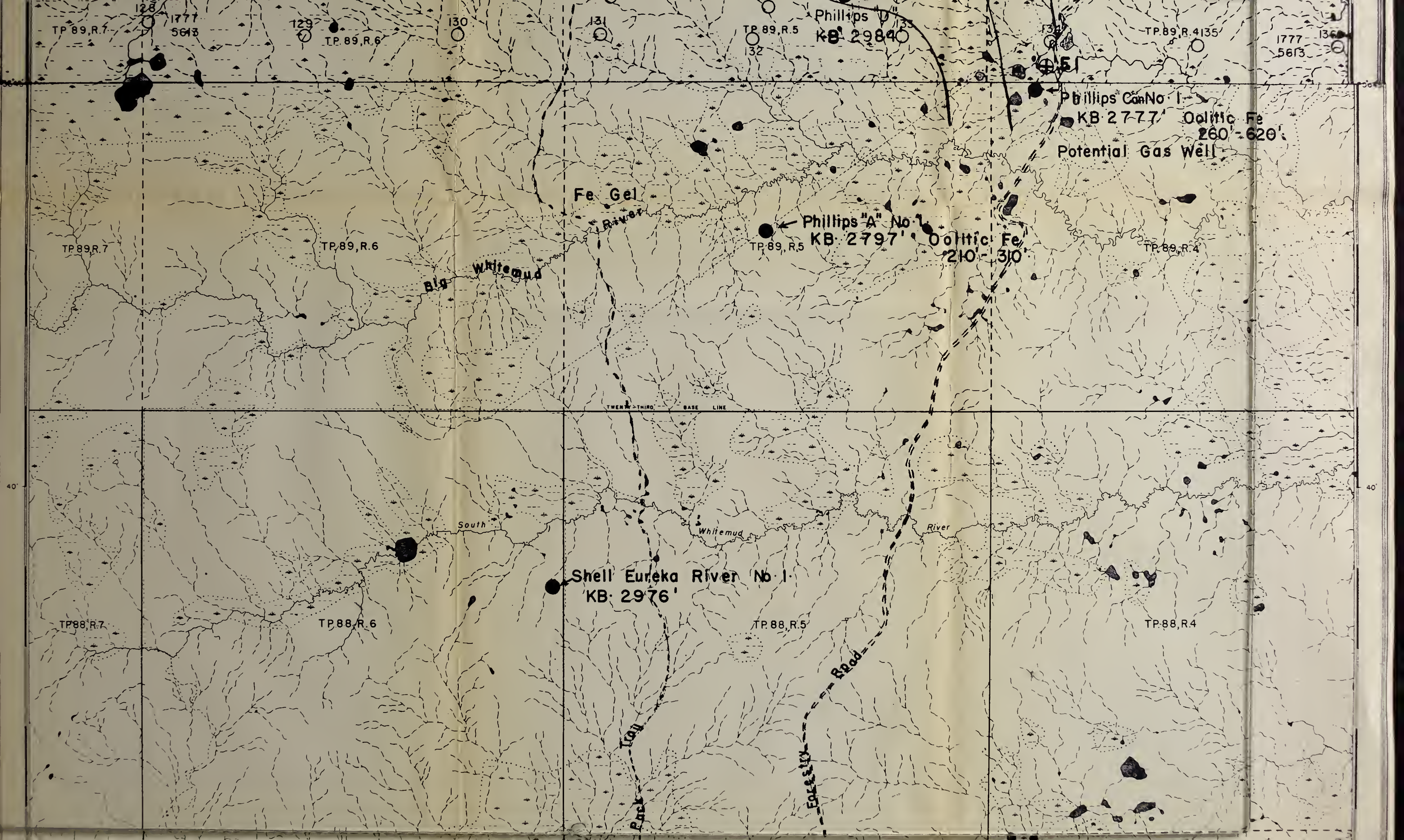
B. - Fossil fragment? replaced by collophane, Pit No.2, Contact Creek, Highwood River area. Thin section 3106 - 180 diameters

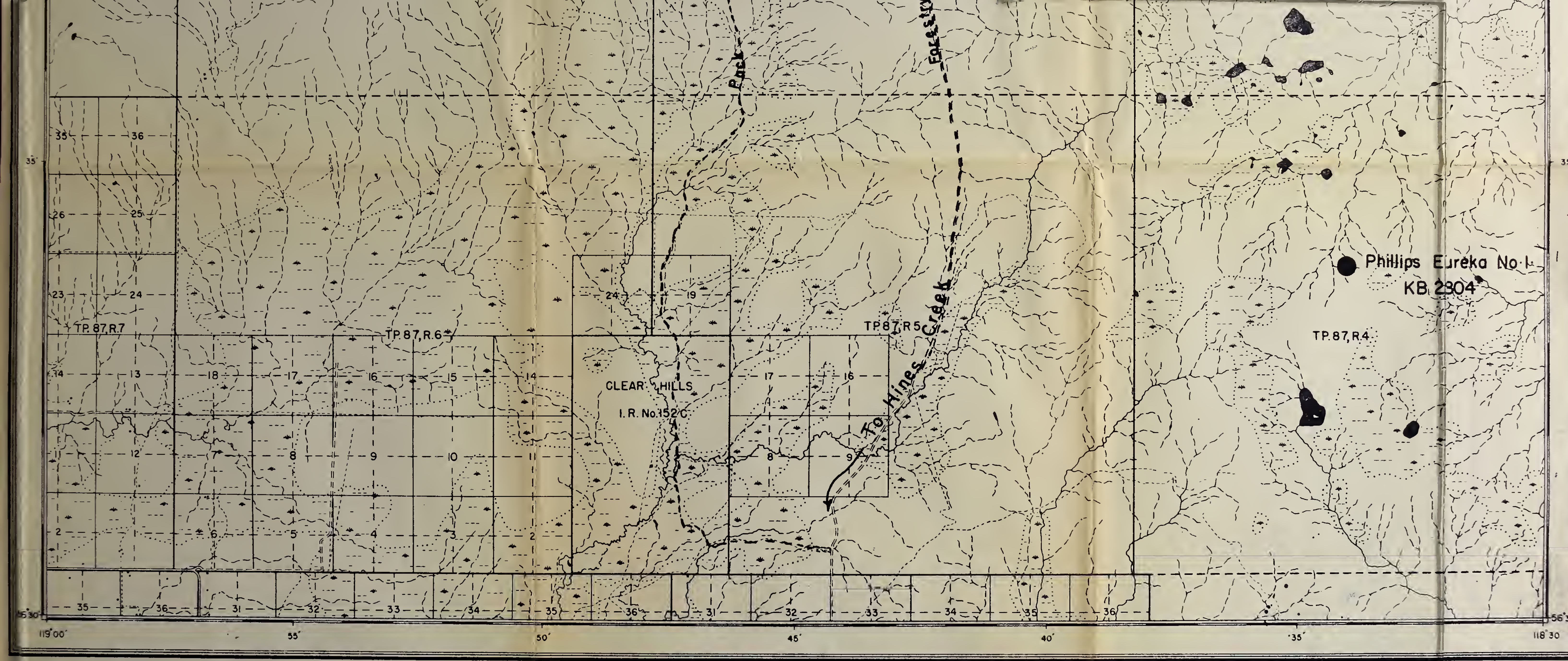





119°00'
55'
50'
45'
40'
35'
118°30'
5700
55
Notikewin
Notikewin
River
Notikewin
R
55
1658
5700
56
57
58
59
60
61
62
63
1658
5700
TP 92, R 7
TP 92, R 6
TP 92, R 5
TP 92, R 4
×Bog Fe
1624
5616
58
59
60
61
62
63
64
65
1624
5616
0
5
10
15
20
E7
E9
E6
E8
E5
E10
E4
E3
E3A
PROBABLE LIMIT OF EROSION
1654
5615
24
25
26
27
28
29
30
31
TP 91, R 7
TP 91, R 6
TP 91, R 5
TP 91, R 4
Deep Creek
1654
5615
Eroded Fe Bed
?
?
Phillips 'B' KB2530'
ISOPACHS ON OOLITIC Fe
(McDougall, 1954)
Oolitic Fe
Outcrop Area
Swift Creek
Notikewin Forestry Tower
A
B
Sample
Locations
1957
Fe Gel
Swift Creek
136
1654
137
138
139
140
141
142
143
1654
144


E5
E10
28
29
30
31
1654
5615
Eroded Fe Bed
Phillips "B" KB2530'
E4
Oolitic Fe
Outcrop Area
ISOPACHS ON OOLITIC Fe
(McDougall, 1954)
Notikewin Forestry Tower
Swift Creek
A
B
Sample Locations 1957
Fe Gel
E3A
E3
136
1654
5614
137
138
139
140
141
142
143
144
Swift Creek
Phillips "C" KB 3042'
TP.90,R.7
TP.90,R.6
TP.90,R.5
TP.90,R.4
1842
5613-148
108
109
110
111
112
113
114
115
116
117
Pack Trail
Phillips Branch No 1
KB 2714
Oolitic Fe
190'-270'
E2
2064
5613-148
58
60
61
62
63
128
1777
5613
129
130
131
132
133
134
135
136
TP.89,R.7
TP.89,R.6
TP.89,R.5
TP.89,R.4
Phillips "E" KB 3028'
Phillips "D" KB 2984'
E1
Phillips Can No 1
KB 2777'
Oolitic Fe
260'-620'
Potential Gas Well
50'


128
1777
5613
TP 89, R.7
129
TP 89, R.6
130
131
TP 89, R.5
132
Phillips "D"
KB 2984'
134
TP 89, R.4
135
1777
5613
136
51
Phillips Can No 1
KB 2777'
Oolitic Fe
260'-620'
Potential Gas Well
Fe Gel
Big Whitemud River
Phillips "A" No 1
KB 2797'
Oolitic Fe
210'-310'
TP 89, R.7
TP 89, R.6
TP 89, R.5
TP 89, R.4
TWENTY-THIRD BASE LINE
40'
40'
South Whitemud River
Shell Eureka River No 1
KB 2976'
TP 88, R.7
TP 88, R.6
TP 88, R.5
TP 88, R.4
Forestry Road
Pack Trail



Published 1951 *Revised 1956*

Compiled from air photographs taken in 1950 at a scale of 1/40,000 (3,333' = 1 in)

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REFERENCE

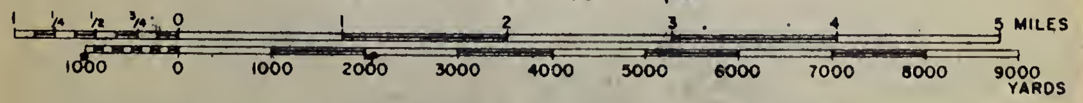
DIAMOND DRILL HOLE	⊕E2
MAIN ROADS	
SECONDARY ROADS	
TRAILS	
RAILWAYS DOUBLE	
RAILWAYS SINGLE	
TOWNSHIP LINE SURVEYED	
TOWNSHIP LINE UNSURVEYED	
SECTION LINES	
QUARTER SECTION LINES	
FOREST RESERVE BOUNDARY	
TRANSMISSION LINE	
TELEPHONE OR TELEGRAPH LINE	

FIGURE - 2

WEST OF SIXTH MERIDIAN

ALBERTA

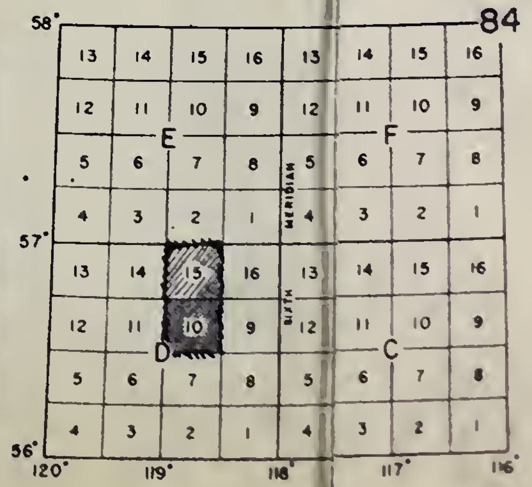
Scale: One Inch to One Mile = 1/63,360



CLEAR HILLS MAP AREA OF ALBERTA

REFERENCE

GASWELL	●
OIL PIPE LINE	
GAS PIPE LINE	
RIVER & LAKE	
INTERMITTENT LAKE & STREAM	
HIGH WATER MARK	
DITCH	
SAND OR MUD	
SWAMP	
CHURCH	SCHOOL
FORESTRY CABIN	▲
FORESTRY LOOKOUT TOWER	
SAW MILL	



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